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July 2010

Shark Predation on Hawaiian Monk Seals: Workshop II & Post-Workshop Developments, November 5-6, 2008

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National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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EXECUTIVE SUMMARY

This technical memorandum is divided into three sections. Section 1 summarizes the proceedings of the second workshop on *Shark Predation on Hawaiian Monk Seals* sponsored by the Hawaiian Monk Seal Research Program (HMSRP) of the Pacific Island Fisheries Science Center (PIFSC) and also the Pacific Islands Regional Office (PIRO) of the National Marine Fisheries Service (NMFS). Section II reviews knowledge to date about shark predation on preweaned and newly weaned monk seal (*Monachus schauinslandi*) pups and NMFS' mitigation attempts at French Frigate Shoals (FFS) and elsewhere in the Northwestern Hawaiian Islands (NWHI). This section also provides a more comprehensive picture of the issues than time permitted at the workshop. Section III summarizes HMSRP's premises about the nature of shark predation based on peer-reviewed science, inferences, expert opinions, and field experience. HMSRP's positions on controversial aspects of the issue are stated, and a number of appendices are included that detail plans to be executed in 2009 and mitigation ideas for the future.

Section I. Workshop II Report

Workshop II was held on November 5-6, 2008 in Honolulu, Hawaii. Participants included representatives from PIFSC, PIRO, Papahānaumokuākea Marine National Monument (the Monument), U.S. Fish and Wildlife Service (USFWS), State of Hawaii Department of Land and Natural Resources (DLNR), Marine Mammal Commission (MCC), and the Hawaiian Monk Seal Recovery Team. The primary goal of this workshop was to exchange ideas and opinions from different management and scientific perspectives about the predation problem and suggest a logical course of action.

Presentations describing the endangered status of the Hawaiian monk seal, the shark predation problem at FFS, and the first workshop on the issue all set the stage for the second workshop's discussions. Hawaiian Institute of Marine Biology (HIMB) scientists reviewed previous shark research in FFS, reported the results of their 2008 research efforts, and presented their 2009 research plan which was aimed at gathering fine-scale movement data on sharks. HMSRP described 2008 mitigation activities and mitigation strategies for the future. The 2008 mitigation strategy focused solely on the application of a suite of deterrents and devices around Trig Island and the translocation of weaned pups to "safe" islets, although the lethal removal of select sharks had also received support at Workshop I.

Outcomes of Workshop II included an evaluation of previous research efforts, development of definitive statements about the predation problem which was agreed on by all Workshop participants, identification of knowledge gaps, and a prioritized list of suggested actions for upcoming field seasons. Workshop participants advocated improved deterrent design, improved and informed removal of sharks displaying predatory behavior, and a need for analyses on previous data and the collection of additional data on seal and shark behavior. Ideas, such as the use of barriers to keep sharks away from nearshore areas and sonic-tagging pups, were discussed and their implementation recommended.

Section II. Knowledge to Date about the Shark Predation at FFS and its Mitigation

The genus *Monachus* is in crisis; with just two extant representative species, the Hawaiian monk seal offers the best chance of its persistence. However, the Hawaiian monk seal population itself is heading toward extinction. Numerous threats afflict the species across its range. Shark predation on preweaned and newly weaned pups contributes to a unique and extreme situation at FFS that peaked in 1997–1999 and stands out from the trends observed at other sites in the NWHI. Since then, predation has declined to 6-11 pups a year, an unsustainable rate as a result of falling birth rates. Galapagos sharks (*Carcharhinus galapagensis*) and tiger sharks (*Galeocerdo cuvier*) both potentially feed on marine mammals; however, HMSRP has only observed Galapagos sharks attacking and killing pups in nearshore water. Mitigation activities by HMSRP conducted over the last decade include harassment of sharks, intensive observation, translocation of weaned pups, deployment of devices to deter predation, and shark removal.

Section III. HMSRP Premises, Positions and Post-Workshop Developments

HMSRP has developed premises about the identity and number of sharks likely involved, shark wariness to human activity, and opinions about shark culling based on peer-reviewed science, inference, expert opinion and ample experience with the situation at FFS. Post-workshop, HMSRP systematically compared all mitigation actions proposed, detailing the potential benefits and drawbacks based on its premises, positions, workshop recommendations and stakeholders' perspectives. A 2009 field plan was created that includes: (1) logistical and financial support for HIMB shark scientists to conduct shark tagging studies at FFS, (2) the systematic application and comparison of 3 treatments (human presence, deterrents and a control) at 2 pupping sites, (3) the design and installation of a custom-made remote surveillance camera system on 1 pupping site, and (4) additional behavioral monitoring of sharks and seals.

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ORGANIZATION OF THIS TECHNICAL MEMORANDUM

This technical memorandum is organized into three separate sections: Section I. Workshop II Report, Section II. Knowledge to Date about the Shark Predation at FFS and its Mitigation, and Section III. Hawaiian Monk Seal Research Program's (HMSRP) Premises, Positions and Post-Workshop Developments. The first section describes the information, views and opinions presented by participants at Workshop II, along with a summary of the discussion that followed each topic's presentation where applicable, as interpreted by the HMSRP. Each stakeholder or agency perspective is summarized in this section in the form of an abstract authored by their representatives who attended the workshop. The scope and history of the shark predation and its mitigation at FFS was briefly summarized at the workshop; however, a full accounting is detailed in the next section of this technical memorandum.

The second section serves as a reference of the knowledge, inferences, and experiences gathered to date on the issue of shark predation on Hawaiian monk seal pups and chronicles the advances and setbacks HMSRP has experienced in attempting to stem shark predation of monk seal pups over the last decade. At the workshop, it was recommended that some facts, figures and definitions pertaining to HMSRP's understanding of the shark predation issue be included in this report. This section summarizes and consolidates information from many sources: peer-reviewed articles, government reports, and field scientists' experiences. As such, a more complete picture of the issue is available here that was not fully formed at Workshop II because of time constraints.

The third section describes the HMSRP's developments in regards to the recommendations from Workshop II. Prioritized research queries and mitigation options are considered in more detail and plans to execute some of these actions are provided. The latter are organized as individual Appendices and ideas presented here will be modified over time as new insights, input, and information arises with each field season of research.

The views and opinions expressed in the last two sections belong to no one member of the HMSRP; rather, they are communicated to demonstrate the breadth of thinking of the team as a whole. The shark predation issue at FFS has many sides and each mitigation activity has its pros and cons. It is likely valuable to present these different aspects in one report to properly take stock and progress forward on the issue. In this way, these two sections also serve as a reference for stakeholders wishing to gain additional understanding about management decisions put forth by HMSRP in the past and those likely to be pursued in the future.

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SECTION I. WORKSHOP II REPORT

Overview of Workshop II: Goals and Objectives

The second Workshop on Shark Predation of the Hawaiian Monk Seal was held on November 5–6, 2008 on the 11th floor of the Kapiolani Building in Honolulu, Hawaii and was organized and directed by Bud Antonelis, Bert Harting, and Kathleen Gobush of Pacific Islands Fisheries Science Center (PIFSC) of the National Marine Fisheries Service (NMFS); Randy Reeves, who represented the Marine Mammal Commission (MMC), served as facilitator. More than 35 attendees participated, including representatives from the Papahānaumokuākea Marine National Monument, U.S. Fish and Wildlife Service (USFWS), DLNR (Department of Land and Natural Resources), MMC and Hawaiian Monk Seal Recovery Team (HMSRT) and the Pacific Islands Regional Office of the NMFS.

The goals of the workshop were to:

- Improve our understanding of Galapagos shark predation on nursing monk seal pups at French Frigate Shoals (FFS).
- Identify the most feasible, effective and sensitive predation mitigation measures likely to boost pup survival in a timely manner.

The objectives of the workshop included:

- Provide updated information on monk seal population status and shark predation trends.
- Address dual missions of overall ecosystem preservation and specific species recovery.
- Provide updated information on shark ecology studies at FFS.
- Provide an overview of recent predation mitigation activities at FFS.
- Discuss and evaluate nonlethal and lethal approaches to mitigating predation.
- Suggest a preferred course of action for monk seal/shark efforts in 2009.
- Identify additional research needs in regards to mitigation techniques and seal and shark ecology and behavior.
- Address effects of research and mitigation activities on other resources at FFS.

The second workshop on shark predation mitigation was logically built on the outcomes of the first workshop, as reviewed on the first day. Presentations describing the endangered status of the Hawaiian monk seal and perspectives of stakeholders prompted the discussions at the second workshop.

Review of Workshop I

Bert Harting, PhD, Hawaiian Monk Seal Research Program

The first workshop on shark predation mitigation, held January 8–9, 2008, in Honolulu, Hawaii, convened to examine the dynamics and history of Galapagos shark predation on monk seal pups and to investigate the full range of mitigation options that might be applicable to the situation at FFS. Participants included representatives of key agencies with jurisdictions in the

Northwestern Hawaiian Islands (NWHI), Hawaiian cultural specialists, aquatic ecologists, adaptive management specialists, shark ecologists, and researchers with expertise in recent innovations in the field of nonlethal shark deterrents. The history and scale of shark predation at FFS was described, along with inferential evidence about the development and dynamics of the predation issue. Various types of mitigation attempted from 1998 to 2007 were outlined that included harassment, translocation of weaned pups, and removal of predatory sharks.

The three presentations on shark biology emphasized how very little is known about the local population (abundance and life history) of Galapagos sharks, both in the NWHI and at FFS in particular. Available data for this species in the NWHI are based on the few sharks tagged in prior studies or extrapolation of results from other areas that may not be fully applicable to the FFS population. It was agreed that additional research (tagging and other) was needed at FFS to:

- Estimate the abundance of Galapagos sharks engaged in pup predation.
- Determine whether the predators were a quasi-distinct group of sharks or were part of the larger Galapagos shark population that ranged both inside and outside of the atoll.
- Better characterize the shark movements and ecology at the atoll and their behavioral repertoire associated with pup predation.

At the workshop, the shark researchers present at the workshop agreed that the presence of Galapagos sharks in shallow water around pupping sites was not characteristic behavior for the species but could be a distinctive behavioral characteristic of the local (NWHI) population. Presentations on shark behavior and shark predation on pinnipeds in other areas demonstrated the unpredictability of the taxa, in general, and also showed the sharks' ability to learn and adjust their predatory behavior in accordance with changes in pinniped population numbers or distribution.

Presentations on nonlethal deterrents illustrated that several different types of devices hold promise, but participants raised concern about their feasibility of their immediate deployment in a remote, open-water setting. Potential methods discussed at the workshop included magnetic "barriers" placed in the water and the attachment of "mischmetal" directly on seal pups (a mischmetal is an alloy of rare earth elements). Additional discussion, but no presentations, pertained to other possible deterrent types (visual, auditory, and electromagnetic). Of the methods discussed at the workshop, permanent magnets appeared to be the most promising, but the optimal method for deploying these magnets in the field was unclear.

Shark removal was discussed as an option to attempt to immediately reduce the level of predation on monk seal pups. Agency representatives in attendance at the workshop noted, however, that based on the limited success of shark removal attempts in prior years, a new proposal to conduct more removals would require additional scientific underpinnings to gain acceptance. Galapagos sharks had clearly become exceedingly wary of traditional hook-and-line fishing near Trig Island in prior years as inferred from low and diminishing catch-per-unit effort (CPUE) experienced by Hawaiian Monk Seal Research Program (HMSRP) staff.

The best methods for capturing sharks involved in pup predation were discussed. Some shark researchers indicated a short longline (25-hook drumline buoys of 50–100 m) set in shallow water a distance away from a pupping islet (e.g., Trig) was a feasible method. Other workshop participants questioned the accuracy of such methods in obtaining the sharks truly involved in pup predation. Some participants were of the opinion that any shark exhibiting patrolling behavior near pupping sites was among the pool of predators.

Summary of potential actions supported at Workshop I:

- Limited take (method not defined)
- Deterrents (chemical, electrical)
- Nonphysical barriers (visual/auditory barriers)
- Seal pup translocations or relocations
- Behavior modification (of sharks)
- Expanded shark and seal studies

Additional information needed on the following data gaps as defined at Workshop I:

- Characterization of the pool of predators
- Feasibility of each type of deterrent and nonphysical barrier
- Optimum shark removal methods
- Spatial context of predation (i.e., when and where pups are most vulnerable)
- Shark movement patterns (i.e., use sonic tags technology to accomplish this)

Context of Shark Predation Mitigation Actions: Endangered Status and Recovery Mandate
Charles Littnan, PhD and Bud Antonelis, PhD, Hawaiian Monk Seal Research Program

Hawaiian monk seals are facing a crisis, particularly in the NWHI where they are at their lowest level in recorded history. While the abundance and demographic performance of the various NWHI subpopulations has varied historically, in recent years all six subpopulations have either failed to grow or experienced declines. The most current population estimate is 1183 seals, with a minimum abundance estimate the main Hawaiian Islands (MHI) of 83 seals (Carretta et al., in prep.) but more likely in the range of 100–150 seals (NMFS, unpubl. data). Less than 1 in 5 pups survive to adulthood in the NWHI. Estimated abundance is declining by 3.9% annually, with a 66% decline in mean beach counts during 1958–2006 (Carretta et al., in prep) (Fig. 1). Forty-one pups were born at FFS in 2008 versus 120 pups 18 years ago (1990). Despite these grim facts, progress is occurring in terms of HMSRP's partnerships. For example, the Monument has provided protection for Hawaiian monk seals by serving as a buffer to anthropogenic threats to the seals and has brought increased awareness to the monk seal situation. Also, there have been increased positive interactions with stakeholders that have improved partnering, particularly with limited resources.

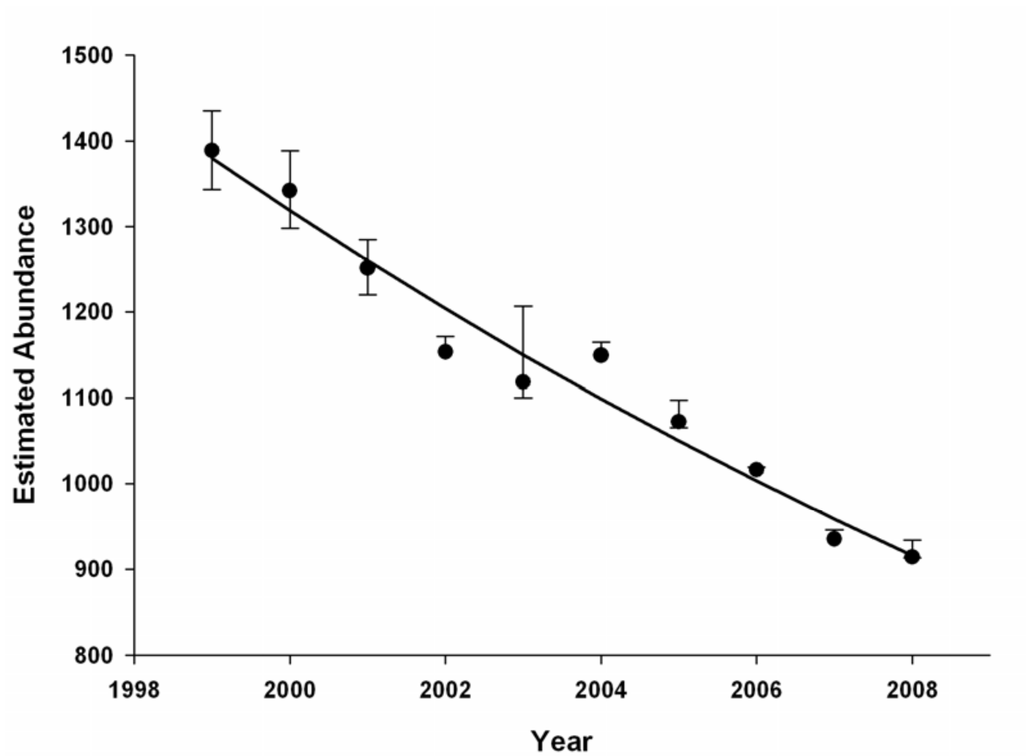

Figure 1.--Decline in abundance of monk seals at the six main NWHI subpopulations based on total enumeration and capture-recapture estimates (Carretta et al., in prep.).

Recovery efforts for proactive mitigation of Galapagos shark predation on preweaned pups at FFS have been based on the use of the best available scientific information. Ideal experiments are difficult to implement as a result of low population numbers, but well designed studies and inference will continue to provide useful scientific information for future recovery efforts. Additionally, HMSRP takes an overarching adaptive approach by incorporating new information for ongoing work and ensuring that the status quo is not maintained if it is not facilitating the survival and reproduction of monk seals. The adequacy of the science supporting implementation of the Endangered Species Act (ESA) has received significant attention over the years (Clark et al., 1994; NRC, 1995). Disputes have resulted from actions for endangered species recovery that have been based on limited scientific information. However, these actions must be implemented by the agencies responsible for enhancing population growth. The ESA mandates apply the best available science to inform management actions (NRC, 1995). An urgency to mitigate threats in order to facilitate recovery of endangered species, including mitigating shark predation of HMS pups, often precludes the ability to gather the best *possible* science, instead relying on the best available science in most cases.

Workshop Discussion

The dual mandate raised concerns at the workshop. For example, it was suggested that a reluctance to take quick, decisive proactive steps for mitigating shark predation as soon as there was enough evidence to proceed might have led to an accumulation of impacts in the FFS ecosystem that may now be irreversible. On the other hand, applying a mitigation action warrants questioning if the study design is insufficient to provide statistically or strong inferential conclusions about the efficacy of the action. These dilemmas have, at times, polarized stakeholders as political agendas, and agency mandates have contributed to mixed interpretations of scientific information. Trade-offs in the immediate recovery and ideal research design of the Hawaiian monk seal provide a real dilemma for scientists and managers charged with recovery of the species and demonstrate the need to have all stakeholders aiding in the decision-making process.

Stakeholder Perspectives

Agencies and groups with a stake in the recovery of the monk seal in the Papahānaumokuākea National Monument shared their perspectives on previous efforts to mitigate shark predation on monk seal pups at FFS as presented here as a brief contributed abstract. Agencies and groups included are: USFWS, the Papahānaumokuākea National Monument, the MMC, and the HMSRT. State of Hawaii DLNR and Hawaiian Traditional Knowledge for the Hawaiian Monk Seal Recovery Team were represented at the Workshop but did not provide formal presentations. Each stakeholder or agency perspective is summarized in the form of an abstract authored by their representative who attended the workshop.

USFWS, abstract authored and presented by Beth Flint

The USFWS, Hawaiian Islands National Wildlife Refuge, and now also Papahānaumokuākea National Monument, consider the dwindling Hawaiian monk seal populations a serious situation. National Wildlife Refuges are managed in accordance with the National Wildlife Refuge System Administration Act, as amended, and other guiding laws and USFWS policy to conserve species and habitats throughout the United States. One guiding principle is to manage refuges so that biological integrity, diversity, and environmental health are maintained. Refuge management is also guided by the use of the best available science in decision-making. Such mandates have resulted in the refuge placing some constraints on the actions of the monk seal managers when the risk of damage to refuge wildlife and habitats was determined to be too high, especially when considered with uncertain alternatives. Additionally, we are concerned that severe ecosystem modification in the form of large reductions in numbers of any other native species (including sharks) may not be feasible, may have unintended consequences, and may not achieve the desired effect. The USFWS supports intervention to recover this species by using the best practical alternative while minimizing collateral impacts. Given the urgency of the population decline and impending demographic crisis, the Refuge acknowledges that decisions are necessary even without all the scientific information we would like, and it may not be possible to recover Hawaiian monk seal populations without dramatic interventions such as captive care for particularly vulnerable age classes. Ultimately, there have been occasional but predictable differences of opinion between Refuge managers and NMFS monk seal managers directly related to the differing responsibilities of each group, but we recognize that our overall goals of recovery are the same, and we will continue to work together to reach that goal.

Workshop Discussion.--USFWS supports intervention and not to just watch nature unfold, realizing that more dramatic interventions may be initiated. USFWS objectives are identical to the HMS Recovery Plan. Large-scale removal of sharks would be difficult to allow given other mandates by the USFWS for the refuge. Randy Kosaki, NOAA Deputy Superintendent from the Monument, mentioned that stakeholders need to be aware that some words used are judgments; words such as "large-scale removal" may be a small number to some and large to others.

The Papahānaumokuākea National Monument, abstract authored and presented by Randy Kosaki, NOAA Deputy Superintendent

No abstract was submitted. Mr. Kosaki described that the draft Management Plan is nearly final and that this document is directly applicable to Hawaiian monk seal survival and recovery. The Management Plan provides good protection for the resources at an ecosystem level. Although it has no direct hands-on mandate to manage seals, the monument has interest in the long-term conservation of a stable ecosystem. According to the mandate for the monument, the reserve shall be managed to further restoration and remediation of degraded or injured reserve resources, and its mission is to carry out seamless integrated management to achieve this objective.

Mr. Kosaki mentioned five activities related to recovery of HMS (listed in the NWHI Management Plan, which references the Hawaiian Monk Seal (HMS) Recovery Plan)

- Remove marine debris.
- Facilitate emergency response (e.g., captive care).
- Conserve habitat.
- Reduce human interactions.
- Provide outreach and education of HMS.

Workshop Discussion.--The Management Plan does not show anything related to increasing HMS juvenile survival; however, the Monument has a role in facilitating the necessary research. The Monument Plan speaks of making the effort to understand shark behavior archipelago-wide. The monument has: (1) helped seek funding to expand the study of Galapagos sharks and the ecology of FFS, (2) supported HIMB shark research for 3 years by complying with the policies of a memorandum of agreement, direct support in fiscal years 2008–2009 including logistical support by ship time in the NWHI. The Monument will provide advice to ensure predation studies are consistent with Monument mandates and will facilitate processing/issuance of permits necessary for shark removal and deterrence in a timely manner.

MMC, abstract authored and presented by David Laist

According to the MMC, the loss of Hawaiian monk seal pups at FFS to shark predation is a significant recovery issue and that action to minimize those losses is a priority issue. The MMC also believes that the working hypothesis by the PIFSC staff, that the problem is caused by few individual Galapagos sharks that have learned this predatory behavior, is a reasonable and likely assessment. The Commission has written letters of support for USFWS shark removal plans in the past. We believe that a limited removal of involved sharks at the numbers requested in the past is a reasonable and appropriate mitigation, and that all options up to and including such an approach, (i.e., including nonlethal forms of shark deterrence) should be explored thoroughly. To date, the Commission has not been asked to consider a large-scale shark removal program, but I suspect it would be less inclined to support that approach given its possible effect on an important reef predator and the atoll ecosystem. Recognizing that the surgical removal of individual sharks has been frustrated by shark avoidance behavior, the future success of any limited removal strategy may depend on our ability to obtain detailed information on shark movement and behavior patterns that could indicate where and when sharks patrolling atoll lagoons might be most vulnerable to being caught. Such information also would be valuable for assessing the validity of the above-mentioned hypothesis and assuring adverse ecosystem effects are avoided.

Workshop Discussion.--Mr. Laist reiterated that the hypothesis that a few individual sharks are the source of predation is sensible and reasonable, and a limited removal (not a large-scale removal) of sharks is agreeable. He emphasized that the solutions to this problem are dependent on understanding the movement and behavior of each species (when and where predation is occurring) and also information that a limited number of sharks are exercising this feeding mode. He described two creative possibilities of behavioral modification: (1) to draw sharks away from the pupping sites by using bait and (2) to use electronic instruments imbedded in artificial shark decoys to shock seal pups as a way of teaching them to associate a negative stimulus with a shark-shaped object. (These suggestions are examined in detail in the Section III of this memorandum.)

HMSRT, abstract authored and presented by Bill Gilmartin

The HMSRT was informed of the increased rate of predation of Galapagos sharks on Hawaiian monk seals at FFS at a mid-1990s HMSRT meeting. At that meeting and since that time, the HMSRT has recommended that NMFS take immediate action to mitigate the shark threat to the FFS population. A primary concern of the HMSRT has been that the behavior may spread within the shark population and increase seal pup losses, hence the recommendation to resolve the problem as soon as possible. With the initial reluctance of the Fish and Wildlife Service to approve lethal takes of sharks without more information on the shark population, the HMSRT also recommended that NMFS initiate the shark population and movement research necessary to resolve these questions. While some limited actions (population research, lethal takes and hazing) had been taken by NMFS, the problem continued unresolved into the mid-2000s, with shark takes beginning to occur at other sites within the FFS Atoll. Immediate action on the shark predation issue is required; shark predation is one of four key actions that are necessary to turn around the species' declining trajectory and foster recovery.

Shark Perspective

Shark ecologists addressed the following topics:

- Global distribution, habitat use, and status of Galapagos sharks
- Movement studies of Galapagos sharks in NWHI to date
- Future research

Galapagos Shark: Global Distribution, Habitat Use, and Status
R. Dean Grubbs, PhD, Florida State University Coastal and Marine Laboratory

The Galapagos shark, *Carcharhinus galapagensis*, is a widespread subtropical-to- tropical species typically associated with oceanic islands. Galapagos sharks are restricted primarily to insular shelves in clear water over hard-bottom habitats (rocky or coral reef) resulting in very patchy distributions across ocean basins. Little is known regarding the population structure of this shark species, although this is an area of active research. It is likely that multiple allopatric populations exist within ocean basins. Recent research has suggested that significant population isolation may occur over relatively short distances. For example, 300 Galapagos sharks were tagged in 100–200 m of water and none in shallow water (presumably because the species did not frequent shallow waters there) near Bermuda (Kohler et al., 1998). Fourteen individuals were recaptured and only 2 had traveled northward up to the US coast. This level of movement is indicative of a population structure that is localized and resident.

Galapagos sharks are listed globally on the World Conservation Union (IUCN) redlist as near threatened (IUCN, 2008). However, this is a precautionary listing as Galapagos sharks have been listed as Data Deficient in all regional assessments based on a lack of data concerning life history and abundance trends as well as problems with misidentification. Critical data gaps regarding the life histories of Galapagos sharks hinder attempts to model population growth rates, resilience, and doubling times. The only published life history data for this species likely include parameter estimates that are in serious error. Galapagos sharks are found throughout the Hawaiian Archipelago, but are most common in the NWHI in areas where water depths are 30 to 50 m. The highest catch rates (number of sharks per 100 hooks) of Galapagos sharks in deepwater locations in the NWHI are FFS 8.1, Midway 16.2, and Maro 36.2 (Lowe et al., 2006). The genetic structure of the Hawaiian "population" is currently being investigated, but many more samples are needed. Gut analysis findings indicate that the typical prey for Galapagos sharks includes demersal, benthic prey such as lobster, fish, and octopus (Wetherbee et al., 1996).

Movement Patterns of Galapagos Sharks in Hawaiian Waters
Carl Meyer, PhD, HIMB (Colleagues in attendance included Kim Holland, PhD, Yannis Papastamatiou, PhD, and John Dale)

Knowledge of shark behavior in the NWHI Archipelago is primarily based on the results of several studies conducted over the last decade using sonic tag/acoustic transmitter technology, including:

- Galapagos/Tiger shark studies 2000–2003:10 Galapagos sharks were tagged (see methods described below) at Midway and FFS, including 4 that were tagged close to Trig Islet (although hundreds of hours fishing occurred at Trig) (Lowe et al., 2006).
- Monument top predator movement studies 2005–2007: 65 Galapagos sharks were tagged across NWHI (in deep water), including 13 tagged outside of FFS Atoll, including 4 individuals with satellite tags; long distance movements were rare (1 Pearl and Hermes Galapagos shark travelled to FFS, a 1257 km distance). Long-

distance movements by Galapagos are rare, suggesting they are very site attached (meaning atoll-resident). (Meyer, unpubl. data).

- MHI shark cage study 2007: 25 Galapagos sharks were tagged on Oahu. Receivers intercepted only two inshore signals out of thousands of signals total; these sharks tended to move along the depth contours (Meyer, unpubl data).

The latest study was initiated in June 2008 to determine the spatial dynamics of sharks, especially with respect to monk seal pup movement, behavior, and birth/nursing sites to better understand predation and identify effective mitigation strategies. The aim is to determine where, when, and which sharks are visiting pupping sites and length of visit. The results of broad-scale movement patterns of sharks tagged as a part of this study are not expected to be available until 2010. To date, 12 Galapagos sharks and 9 tiger sharks (*Galeocerdo* cuvier) have been tagged. The sharks were captured using 10-hook longlines outside of the barrier reef in the deep lagoonal areas (70–80 m depth range) across 11 days in June and July 2008. Tagging effort in shallow areas yielded no catch. Data examined to date indicates that in contrast to tagged Galapagos sharks, tagged tiger sharks are moving throughout the FFS Atoll. However, there may be a subset of Galapagos sharks that may be using the atoll that the HIMB did not catch in this effort.

It is difficult to determine predictable patterns of movement of Galapagos sharks in FFS presently, because of the small tagged sample size. Thus far, highly individualized movement patterns result in noisy data. Within atoll movement by Galapagos sharks tagged to date: they primarily travelled north to south; only one individual shark always remained inside atoll. Of 3 Galapagos sharks tagged in 2007, the sharks visited Trig Island initially and then stopped. The following are conclusions about Galapagos sharks within FFS: (1) they are primarily resident at atolls, (2) generally uncommon inside the FFS lagoon, and 3) their behavior patterns are variable among and within individuals over time. However, there is evidence of core area use by some individuals.

The CPUE (per hook hour) of Galapagos sharks at FFS over time is as follows across three habitat types:

(1) Shallow lagoon (few meters depth and within 100–300 m of pupping sites)
- 2002–2003: 0.015 sharks
- 2005–2007: 0 sharks
- 2008: 0 sharks

(2) Deep lagoon (west of La Perouse and south of Shark Island, approximately 25 m depth)
- 2008: 0.04 CPUE

(3) Outside barrier reef (50–100 m) depth
- 2005–2007: 0.4 sharks
- 2008: 0.15 sharks

Future Research

The following key behavior questions need to be addressed:

- Is the FFS Galapagos shark population wide-ranging or site-attached?
- Are predictable patterns of movement and habitat use discernable?
- Are a few or many sharks (a broad swath of the population) involved in predation of monk seal pups?

Methods used to answer these questions center on acoustic tagging of Galapagos and tiger sharks at FFS. The core tracking technology used is acoustic monitoring and involves a small transmitter implanted in a shark. Underwater listening stations receive a signal from the transmitters (tags) indicating the date, time, and individual animal that passed by the receiver. An acoustic array now exists from MHI to the NWHI. Coverage will be increased in 2009 in the NWHI. Currently, clusters of receivers are located throughout the NWHI, with a concentration around FFS. At FFS, receivers are presently located at Tern, Trig, Round, East, Gins, Rapture Reef, La Perouse, and one north of Tern outside the atoll. The detection range of receivers is habitat-dependent and is typically < 100 m in complex reef. Tag transmitters have a battery life of nearly 2 years.

The goals for the HIMB research effort on Galapagos sharks at FFS in 2009 are to:

- Deploy more tags and receivers to increase confidence; spaghetti tags will also be deployed for later shark identification and observational purposes.
- Stratify the fishing effort to cover both inside and outside of the FFS Atoll. All three habitat types will be included to determine if sharks in shallow water are a subset of the population.

Shark population size studies are not feasible for the 2009 field season but may be possible in 2010 or later. See Appendix B for a detailed description of the 2009 HIMB Shark Tagging Research Design submitted by C. Meyer, PhD.

Additional information regarding shark movement and behavior around pupping sites at FFS is provided in Section II of this memorandum.

Workshop Discussion.--A general discussion about sonic tagging methods ensued, as well as the following questions and answer session by Dr. Meyer. When asked what can be said about Galapagos sharks at FFS today if no additional shark research was conducted, the reply was that the lagoon is probably only in the periphery of the home ranges of adult Galapagos sharks. As to the question if there are few or many sharks available inside the atoll, the reply was that the data are consistent with few sharks available inside the atoll because of low CPUE (inside is interpreted as shallow and deep lagoon). Dr. Meyer said there is probably a subset of individuals exhibiting the pup predation within the lagoon at FFS that are adults (sharks as they age undergo ontogenetic diet shift since only older sharks can target marine mammals). Regarding learning to feed on marine mammals, sharks are not social and will eat their offspring; the feeding behavior of sharks is basically exploratory and not transmitted between individuals. If a shark is successful in obtaining prey then it will repeat the behavior. Sharks adapt to changing circumstances. Regarding recapturing sharks, it is very individualistic; for example, a single tiger shark was only recaptured after five attempts, whereas another was recaptured on the first try. Regarding the poor success in capturing Galapagos sharks near Trig Islet in the past (presumably efforts by HMSRP and HIMB), it was explained that Galapagos sharks just have not been frequently seen in the area where gear has been set. If deterrents are applied and shark movement change is detected, cause and effect will be difficult to discern, because sharks may have been intending to vacate any area on their own anyway and not necessarily in response to the deterrent itself.

Hawaiian Monk Seal Perspective

The following topics were presented on the HMSRP's shark predation mitigation efforts in 2008:

- Description and results of the deterrent and device trials
- Evaluation of successes, challenges, limitations encountered and expected in mitigating Galapagos shark predation in the future

Summary of Shark Deterrent and Non-Physical Barriers Deployed at FFS, 2008
Kathleen Gobush, PhD, Hawaiian Monk Seal Research Program

In 2008, HMSRP deployed a suite of implements that included electromagnetic and magnetic deterrents and auditory and visual devices based on the recommendations from Workshop I (NMFS, in prep.). For this pilot study, HMSRP decided that the suite approach was the most logical means to test the feasibility of these devices and protect the most pups. Alternatively, each device could have been deployed one at a time to test its effect; however, the total expected number of incidents across the short window of time of application (confined to the pupping season, late May–August) would preclude robust statistical analysis. Thus, it was decided that, initially, a suite of devices would be applied with the option to incrementally remove or add certain devices in future trials based on preliminary observations made during the pilot study. Devices deployed with possible shark deterring capability included:

- Ceramic magnets
- Shark Shield ® electromagnetic devices

Auditory and visual devices deployed included:

- Boat sounds emitted underwater
- A small, anchored boat
- Floats and buoy array, deployed in association with the ceramic magnets

Magnets and electromagnetic devices exploit the capability of elasmobranchs to perceive electromagnetic fields with their ampullae of Lorenzini. These are gel-filled pores homogeneously distributed around the nose and mouth of the shark. In the presence of an electric field, the electric potential at the surface of the prey differs from the electric potential of the interior of the animal, which is detectable by the shark (http://www.shark.co.za). Galapagos sharks are less likely to bite bait in the presence of large electric fields (Stoner and Kaimmer, in press), so items which create such fields may serve as repellents. Both the cermaic magnets and Shark Shields artifically create electromagnetic fields in water. Magnets are expected to be detectable by sharks at a distance of approximately 20 cm and the Shark Shields at 5 m (See Section II for clarification) (http://www.sharkshield.com). Shark Shields use “electronic wave-form” technology invented by the Natal Shark Board of South Africa. The main advantage of such a system, as compared to permanent magnets, is that it is likely to have a more powerful deterrent effect near the point of deployment. The device is described as posing no risk to non-elasmobranch species, because the high electrical conductivity of salt water is less resistive than living tissue and the electroshocking current would flow around them. Shark Shields have an output of approximately 80 volts. The Shark Shields are powered batteries with 7 hours of life between charges.

Auditory and visual devices are believed to replicate sounds and sights produced by humans. The expected utility of these decoys or human proxies is based on the HMSRP’s past observations and inferences about shark wariness (See Section III for further discussion). The recorded sounds emitted with the auditory devices also have the potential to provide a negative stimulus for sharks based on their frequency range (Myberg, 2001). Field and laboratory experiments have demonstrated that sharks can hear sounds with frequencies ranging from about 10 Hz (cycles per second) to about 800 Hz, but are most responsive to sounds less than 375 Hertz (Myberg, 2001). Ambient noise generally ranges from 60 to 90 decibels, over a frequency range of 1 to 20,000, although it can reach 130 decibels during heavy rain for example. Therefore, HMSRP predicted that the sounds emitted would occasionally be masked by ambient sounds. However, it is still likely to provide a negative stimulus if a shark was in close proximity.

Twenty magnet-float sets were constructed, each consisting of a large anchor, heavy poly line, a ceramic magnet, and a surface float. Magnet-float sets were spaced approximately 50 cm apart with their anchors set on sandy substrate. The float portion of each set was placed on the surface or within the water column near shore in 2 m to 3 m of water. The 20 sets were arranged in a staggered pattern, concentrated along the shoreline in the probably zone of shark activity (i.e., patrols and attacks). The aim of this design was to create a visual array combined with a negative stimulus to deter sharks from the area.

Three Shark Shields were deployed in an array across the shallow (1.5 m) sand flat on the north side of the island perpendicular to the beach at Trig Island. The Shark Shields were attached to surface floats anchored by chain to heavy bottom anchors placed on sand substrates. The units were activated between 1630 and 1700 hours. Field staff tested and confirmed that a shock equivalent to that of a moderate electric fence was generated when in direct contact with a unit in the water. No direct observations or indirect evidence of the devices shocking any wildlife occurred. The aim of the design was to maximize the likelihood of a shark encountering the limited number of Shark Shields when engaged in typical shoreline patrolling behavior. The Shark Shields began to fail less than 2 weeks after deployment; all units failed by mid-season.

Three underwater speakers broadcasting simulated boat noise were deployed at Trig, Gin and Little Gin Islands. Speakers were suspended by a surface float and anchored by chain on sandy substrate. All speakers were located within 10–20 m of the shoreline in 2–3 m of water and wired to a transmission unit (amplifier) and a power station on the islands. The transmission unit, a Lubell LL916 transmitter, has a maximum output of 180dB at 1k Hz and frequency range of 200 Hz to 20 kHz. All cables were taut when placed under water and buried when on land to minimize the potential for entanglement. The boat noise emitted, consisting of four unique sounds each 28 to 49 seconds in length that played on a rotating basis for approximately 15–20 minutes each hour for 24 hours per day, was believed to be within the frequency range known to deter sharks.

An empty 15-ft twin hull boat (Livingston) was moored off the northeast side of Trig Island. The bow was secured into the prevailing weather and attached to a heavy concrete mooring anchor placed on a sandy substrate.

Summary of Pup Losses at FFS, 2008
Kathleen Gobush, PhD, Hawaiian Monk Seal Research Program

In 2008, 12 (30%) of 41 preweaned pups in FFS either died or disappeared, with 6 (3 Gin pups and 3 Trig pups) of the losses attributed to sharks (confirmed or inferred–see definitions in Section II). An additional pup was bitten at Trig resulting in 25% (4 of 16) of the pups born there affected by shark predation. Shark depredations were catastrophic on the two Gins Islets in 2008, with 3 losses to sharks out of 6 births and an additional nonlethal but multiple bite wound attack on a pup. The disappearances of 3 other pups (1 from Gin Islet) were categorized as unknown because they were born late in the season after routine data collection had ceased, but shark predation could not be ruled out. In 2007, at least 7 of the 43 preweaned pups born at FFS were lost because of shark predation, and 1 severely bitten pup died post-season because of the extent of its wounds. Overall numbers lost in 2008 did not differ greatly from those of 2007 when devices to deter sharks were not deployed. However, unlike 2007, the site that accounted for the most predation in 2008 was Gin, rather than Trig.

Based on the number of shark incidents in 2008 as compared to 2007, the results of the device trials were equivocal. However, when the number of confirmed and inferred shark attacks across the season was examined against the deterrent effort (a simple index of the cumulative number of deterrent types and individual devices of each that was operational each day), more incidents were associated with diminished deterrent effort at Trig (Fig. 2). Of the 4 shark incidents at Trig, 2 occurred during the ramp-up period of device deployment and 2 at a later time when some of the devices were nonfunctional.

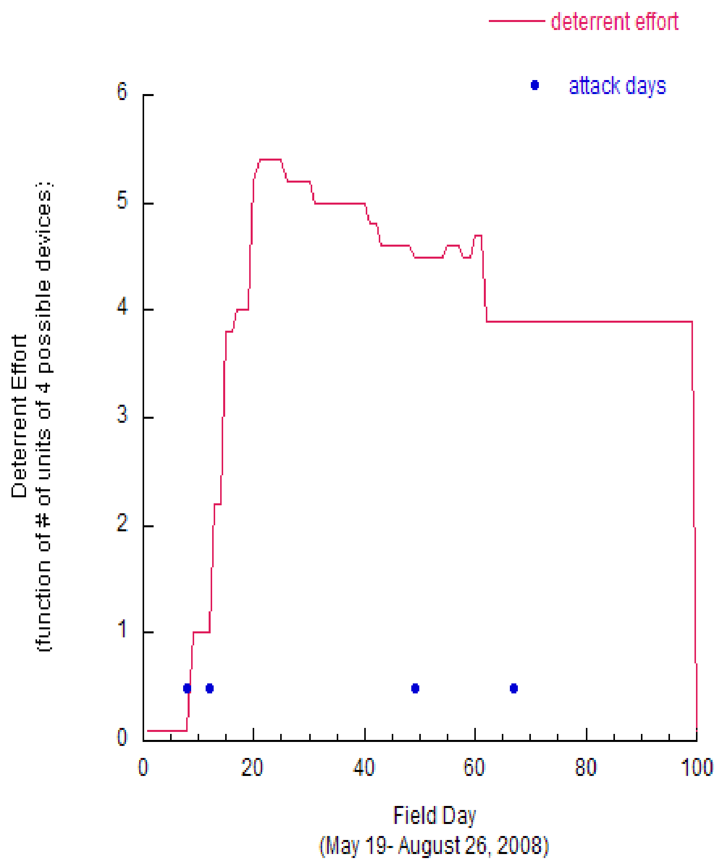

Figure 2.--Deterrent effort as a function of the number of devices operational (electromagnetic, magnetic, visual and auditory devices) and days of shark attacks on pups at Trig Island across the field season.

Workshop Discussion.--A lack of a control treatment and the suite approach were cited as design shortcomings resulting in an ineffective way of testing the efficacy of each device. HMSRP responded that the suite approach was consistent with the mandate to recover the species. Questions about the location and time of predation were asked; however, most of the losses in 2008 were cases of inferred shark predation, and the actual details of the predation events were not observed. Since the inferred attacks occurred when field staff was not present to observe the event, it was interpreted that attacks likely occurred at night or in the predawn hours outside of typical field staff patrolling time. It was suggested that the observation tower be erected again; previously, it was only permitted in daylight hours. Examining tagged shark movements in response to times at times of device deployment in a single pupping season was suggested. Questions arose about any of HMSRP's previous analysis of shark activity and its covariates. Of all covariates tested to date, density of mother-pup pairs was only weakly positively related (see additional details in Section II) (Hayes, 2002; Harting et al., in prep.).

It was suggested that the tracking of pups was needed to have fine-scale measurements of how far they are going offshore, to what depths, and how much time was spent in the water to target the placement of devices in the future (see details in Section II). Typical pup behavior was described as thermoregulating in shallow, nearshore waters and not venturing a far distance from land in the day or night. Instrumenting preweaned pups with sonic tags to pinpoint their movements was suggested, despite the fear of disrupting the mother-pup bonding. Possible methods of attempting to apply sonic tags to pups without restraining or even waking them were discussed. Fencing off areas of the island and nearshore waters was also discussed to pen in pups while not impeding older seal and turtle movement to land.

Future Research

The primary goals of the 2009 mitigation effort include a reduction in predation of preweaned pups and an increased understanding of pup and shark movement, behavior and temporal and spatial overlap. Translocation of weaned pups from Trig and other pupping sites with frequent incidents to Tern would continue. However, action to protect preweaned pups is needed.

NMFS provided three short-term approaches to mitigate predation and several areas of long-term research based on input by workshop participants:

(1) A deterrent-only approach requires reapplication of some of the devices from 2008 in an improved manner around Trig and other islets. The choice of devices to apply in 2009 would be based on the prioritization and suggestions of the workshop participants. For example, to optimize the deterrent application the following recommendations were suggested: (a) establish an earlier start date and longer duration time, (b) include a control treatment, and (c) fine-tune the sound tracks of the auditory deterrent to increase the likelihood of providing a negative stimulus to a shark and reduce the likelihood of habituation by sharks (variable tracks, high-end frequency of sharks' hearing range, pulsed or startling sounds included). Single deterrent field trials in the MHI with wild Galapagos sharks could also inform these improvements.

    A deterrent-alone approach may be insufficient because, thus far, our designs have not proven to conclusively alter the presence of patrolling Galapagos sharks around pupping sites or to influence their predation success atoll-wide. The success of a suite of devices deployed in 2008 was equivocal. It is unknown whether the devices themselves were ineffective or under-effective, and some optimization might improve their utility. It is unlikely that the devices can be consistently applied to all pupping sites where shark incidents occur because of logistical and ecological constraints (i.e., some islets have greater wave action and are located farther way from the base station at Tern making deterrent installation and maintenance more difficult).

(2) A combination approach of deterrents and surgical removal of Galapagos sharks observed patrolling in the area requires the above-mentioned improvements as well as a method and permit for the removal of a limited number of Galapagos sharks. Combining the deterrent approach with an option to remove sharks observed in shallow waters near pupping sites (approximately 1 mile) may offer necessary added protection. This dual focus may ensure that fewer sharks approach pupping sites, thus mitigating the total possible number removed from the ecosystem with this approach. On the other hand, this dual focus may confound efforts to test or develop deterrents if fishing for sharks were to confound deterrent experiments. Tagging efforts by HIMB may also be

negatively effected by removals. Conditions could be placed on removal; for example, a condition that sharks would not be killed until a pre-set number of pups had been lost in a given season by a specific date or sharks caught with transmitters would be released rather than removed.

(3) A conditional multiphased approach involves initial deployment of deterrents combined with surgical removals. These activities would be complemented by an expanded take of a larger number of sharks by a less specific method if certain conditions, such as the following, were met: (a) pup loss is not stemmed by the other methods by mid-season and (b) tagging research supports the hypothesis that a small number of site-attached Galapagos sharks are in the atoll. In this second phase, a stepwise increase in the number of sharks removed would occur if there is a corresponding decrease in a sensitive metric, such as number of shark visits per pupping site per time period. This measurement would require increased research observation (direct observation or acoustical tagging) and/or remote camera recording.

Alternatives to these approaches include developing new deterrents and/or barriers to pupping, relocating mothers who habitually lose pups to sharks to less risky atolls, and restoring submerged pupping sites such as Whaleskate Islet. These alternatives would require additional research and development prior to implementation.

See Section III. Post-Workshop Developments and Appendix D for pros and cons of each device and mitigation strategy.

Workshop Participants' Evaluation of Current and Future Mitigation Efforts

Participants endorsed the following priorities; the discussion surrounding each is summarized below:

1. Pursue shark population/movements studies.
2. Design/conduct pup movement studies to better define spatial/temporal interface.
3. Implement and possibly improve the boat and boat noise deterrent.
4. Conduct a limited, focused removal of individual Galapagos sharks.
5. Locate people on island to guard pups and harass sharks.
6. Address/investigate a physical barrier with Shark Shield units at choke points around Trig.

Further discussions involved the following:

(1) Additional basic information about shark biology at FFS is fundamentally needed to resolve the question as to whether pup predation is limited to few shallow-feeding Galapagos sharks or the problem is too widespread to consider lethal take as a solution. Stratification of the shark-tagging regime that includes sharks frequenting shallow waters is sorely needed despite an expected poor CPUE in shallow waters.

(2) Concise information about pup movement patterns could inform deterrent or removal tactics and deterrent/device placement. The distance pups swim from shore, their coordination with their mothers, the frequency with which they enter the water, and the times of day they are attacked all need to be substantiated by mining previous data, collecting additional nocturnal data and cataloging shark incidents in a standardized way. Preweaned pups could be fitted with sonic tags in order to track their movements and any coincident swimming with tagged sharks.

(3) The use of the array of deterrents and devices and the application of a “suite of devices” were viewed with skepticism, with the exception of the use of the anchored boat and boat noise. It was suggested that each device be tested in isolate on free-ranging Galapagos sharks during the off-season or at another location (not when preweaned pup safety was at risk). Another approach discussed was the application of a suite of devices initially; and if shown to be effective, one device type (visual, auditory, electromagnetic) at a time would be removed. A stratified approach was also discussed, whereby different deterrent types would be applied to different pupping sites. Low sample size (few pups born at some sites and low numbers of incidents) was mentioned as a confounding factor to such analysis. It was suggested that each deterrent and device be tested individually to determine its effectiveness and feasibility in influencing shark behavior; this research could be gone on free-ranging Galapagos sharks in MHI waters.

(4) Removal methods were discussed and HIMB’s methods (depths, bait, gear) for tagging were endorsed as likely to be adequate for HMSRP’s removal efforts in shallow waters. Longer soak times and deeper sets would lead to greater catch rates; even HIMB’s methods are expected to lead to few returns in shallow waters. For this method, the gear, the timing, and location of fishing would lead to minimal bycatch. The following concerns were also expressed: (a) lethal take of offending sharks near pups is likely to be small and insufficient to provide much protection for pups, (b) the opportunity cost of pursuing permits and the actions necessary for lethal removal are large; these resources may well be better spent for the recovery of HMS elsewhere, and (c) shark experts and HMS experts differ in their thinking, experience and/or grasp of the issues.

(5) Placing field staff camp on island to guard pups and harass sharks was discussed. The fact that shark predation has not historically been a problem at Tern Island, where human presence is common, was mentioned as possible evidence that sharks will avoid areas with human activity.

(6) Constructing a physical barrier that would protect pups at their natal sites received support. A semipermeable design with “guarded” openings that allowed seals and turtles to transit to beaches but prevented sharks from entering nearshore areas was also discussed. Electromagnetic deterrents (e.g. Shark Shields) placed at the openings may deter sharks from passing. Concerns were raised about employing engineering strategies to accommodate for wave surge and a possible negative influence on the normal movement patterns of seals and turtles.

(7) Moving mothers and pups together to 'safer' islands (e.g., from Trig to East or Tern) was mentioned but not recommended to be a priority. General support was withheld

because: (a) moving pairs would increase seal density at the receiving island and possibly make it more attractive to sharks, (2) it is unknown if relocated mothers would continue to nurse their pups, and (3) a care facility for abandoned pups may also be a prerequisite for such management activity. One participant suggested removing nursing pups from their mothers and holding them in a captive care situation; this was not discussed further and not recommended to be a priority.

(8) Lastly, a comparative cost-benefit evaluation that addresses opportunity costs (e.g., time, effort, resources, lost seals, decline in population, other recovery projects) of all mitigation practices was suggested to better guide predation management decisions in the future for the greatest likelihood of success given logistic and financial constraints.

Consensus Statements

As a means of evaluating progress to date on understanding shark predation and mitigating its effects on the Hawaiian monk seal population, a moderated discussion occurred whereby several lists of consensus statements and prioritized actions were constructed by the participants in the workshop with each person voicing their opinion (as a representative of their respective agency or institution). Consensus statements were ranked by their certainty (as voted on by the group) as (1) > 90% certain it is true, (2) fairly sure it is true, and (3) unsure and would like to know. Prioritized actions were set in the same manner with the following prioritized levels: (A) high, (B) medium, and (C) low. The consensus statements and action lists are as follows. Full descriptions of the top rated mitigation options and research queries are described in full in the previous page. It was also recommended that these statements be published for reference purposes.

Consensus Statements Regarding Sharks

Human activity deters Galapagos sharks around pupping sights. [1]

Entering shallow water is unusual behavior in adult Galapagos sharks. [1]

If above is true, then removal of the problem sharks at FFS would have a positive effect on preweaned pup survival and, in turn, on the HMS population. [1]

The proportion of observed/confirmed inferred attacks at FFS has declined since the 1990s possibly due to aversion to human activity. [1]

A small sample (even < 5) tagged and tracked Galapagos sharks caught in Trig lagoon would be informative for mitigation. [1]

One-time removal of < 25 Galapagos sharks out of the FFS ecosystem would have no significant long-term negative impact on the shark population. [1]
Predation can occur at different islands in different years. [1]
The Hawaii population of Galapagos sharks is healthy (essentially unexploited). [1]

A small number of specific site-attached Galapagos sharks are responsible for some of the predation on pups at FFS (shortest route needed/power analysis for sample size). [2]

Catching and tagging Galapagos sharks do not significantly alter their behavior and movements (but may be site-dependent). [2]

The Galapagos shark population in Hawaii is a demographically isolated population (population structure). [3]

Tiger sharks are not a significant threat to preweaned pups at FFS. [3]

Consensus Statements Regarding Seals

When in water, pups are located in nearshore areas (day and night). [1]

Attendant mothers attempt to deter sharks while in the water (but this changes as pup matures). [No rank given]

Understanding mother-pup bond determines what you can do to pups to protect them. [No rank given]

Mothers with pups rarely habituate to human presence/activity. [1]

Shark mortality on preweaned pups is not a significant problem at sites other than FFS. [1]

Based on observations since 1982, the problem was not serious at FFS until the mid-to- late 1990s. [1]

Otherwise unexplained preweaned pup disappearances at FFS are largely due to shark predation. [1-seal group; 2-shark group]

Adult male monk seals sometimes kill preweaned (near to weaning) pups; this behavior is flagrant and is being monitored and managed). [No rank given]

Area deterrents have no harmful effect on monk seals (may depend on device type). [2]

Deterrents cause displacement of sharks to other islands/pup sites. [3]

Prioritized Research Queries

Characterize pool of predators. (A)

Determine deterrent effectiveness and feasibility. (A)

Determine optimal removal methods (with training of field staff)—harpoon, bang stick. (A)

Determine spatial context of predation (outside our observational window) intersection of seals and sharks. (A)

Determine shark movement patterns to characterize overlap in time, space and degree with pre-weaned pups. (A)

Perform data-mining past mothering performance. (A)

Perform data-mining past shark interactions. (A)

Refine data collection protocol for shark observations at pupping sites. (A)

Correlate known/inferred pup attacks and tiger shark presence (from tag data). (B)

Conduct experiments to try “ex situ”: shark profiles on nets (C); sharks attracted to recordings of fish in distress (C); light stimulus on shore (C); bubble nets (C), also ‘3’—unlikely effective.

Prioritized Mitigation Options

Accomplish a limited selective removal of problem sharks. (A)

Glue acoustic tags on sleeping pups. (A)

Erect physical barriers to keep sharks away from pup areas. (A)

Restore/modify pupping habitat (restoring Whaleskate). (B)

Conduct an expanded removal (less selective) of Galapagos sharks in monk seal ‘neighborhood’. (C)

Conduct seal relocations—mother-pup pairs; pre-weaned pups of bad moms. (C)

Erect physical barriers—keeping seals out (prevent pupping at risky areas). (C)

Construct physical barriers—keeping seals in (M/P pens). (C)

Prioritized Deterrent Options with Certainty Ratings of their Effectiveness

Anchored boat, moved daily, with speakers broadcasting boat noise. (1) (A)

Speakers with improvements—including variable intensity (volume). (2) (A)

Shark Shields with thoughtful modifications/expansion (barrier with choke points). (1) (A)

Human presence/activity with active harassment/take- maximum presence on islands for as long as possible at as many sites as possible. (1) (A)

Turtle-friendly tensor, floating barrier with Shark Shields in openings (night only). (1) (A)

Broadcasting other noises (killer whales). (2) no priority given

Magnets on floats. (3) (C)

Shark Shields alone. (3) (C)

Prioritized Activities Related to Deterrent Deployment

Record seal injuries and losses. (A)

Use remote video camera to monitor presence of sharks at Trig and Gins
(similar to East Island camera). (A)

If no camera available, dedicate observation time to "deterrent field". (A)

Deploy deterrents at additional islands in step-wise (stratified) manner, coupled with tag monitoring of shark behavior and movement. (B)

SECTION II. **KNOWLEDGE TO DATE ABOUT THE SHARK PREDATION AT FFS AND ITS MITIGATION**

Context: A Genus and Species in Crisis

The endangered Hawaiian monk seal is the best chance of saving the entire genus *Monachus*. The Caribbean monk seal (*M. tropicalis*) was declared extinct in 2008 and the Mediterranean monk seal (*M. monachus*) numbers only a few hundred. The IUCN recently upgraded the status of the species to "critically endangered," a designation reserved for cases where extinction is a real and imminent threat (IUCN, 2008). The range of the Hawaiian monk seal in the NWHI includes the population's six main reproductive sites: Kure Atoll, Midway Islands, Pearl and Hermes Reef, Lisianski Island, Laysan Island, and FFS, plus smaller breeding subpopulations occur on Necker and Nihoa Islands (NMFS, 2007) (Fig. 2). A growing subpopulation exists in the MHI where births have been documented on most of the major islands (Baker and Johanos, 2004). As stated at Workshop II, the population figures for the Hawaiian monk seal in the NWHI are grim. Based on beach counts, the number of seals in the NWHI has fallen to its lowest level on record and less than 1 in 5 pups survive to adulthood.

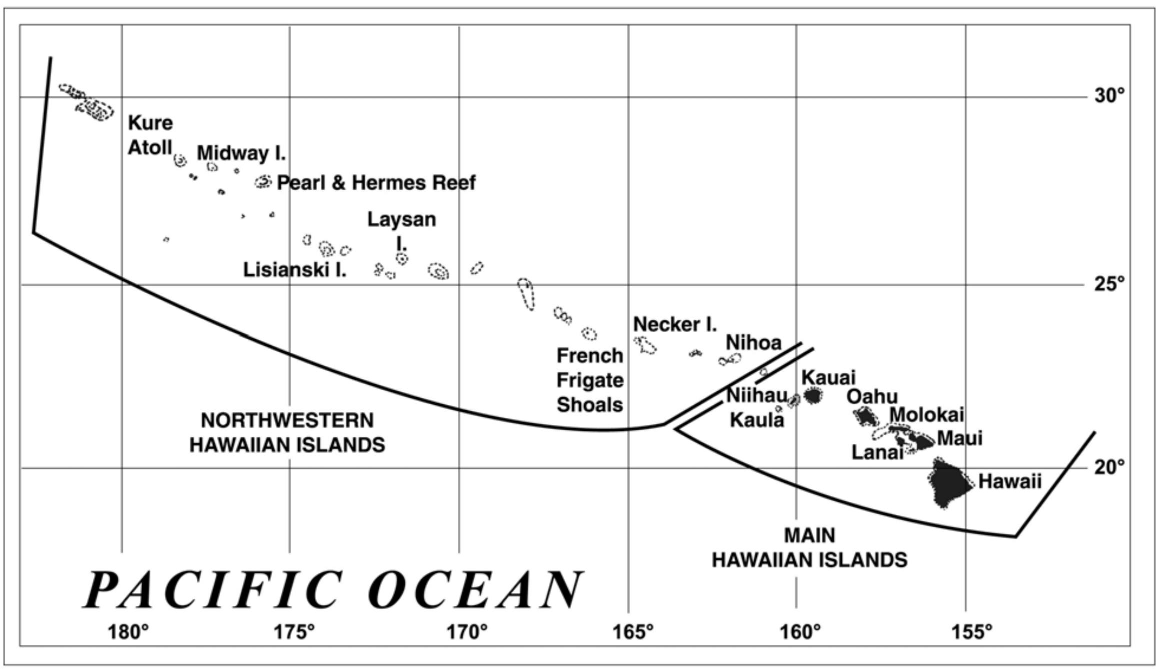

Figure 2.--Range of the Hawaiian monk seal population.

The status and trend of the Hawaiian monk seal population are primarily evaluated using two methods: a "beach count" trend index (mean value from multiple census of all seals present on the beach each season), and direct enumeration of individually identified seals. The beach count index provides a metric for assessing the long-term population trend. Surveys in the 1950s counted more than 900 seals among the six primary breeding populations in the NWHI, whereas comparable surveys in 2008 counted less than 300 seals (Forney et al., 2000; Caretta et al., in prep.). Total population enumeration is available for only 1998–2008 but provides a more precise measure of population decline. For population enumeration, seals are identified using tags, temporary applied marks, and natural features (scars, natural bleaches or other characteristics). The total abundance of seals in the NWHI (not including MHI, Necker, or Nihoa) was approximately 1400 in the late 1990s, but declined to 914 seals in 2008 (Caretta et al., in prep.).

Another key metric for assessing population performance is the number of pups born. This measure varies considerably across years and sites, but since the late 1990s the total number of pups born at the six main NWHI sites has declined from almost 250 in the late 1990s to 138 in 2008 (Caretta et al., in prep.).

Overall, the causes of Hawaiian monk seal decline are numerous and complex and are thoroughly reviewed in the revised recovery plan for the Hawaiian monk seal, which is published by NOAA in compliance with the ESA (Antonelis et al., 2006; NMFS, 2007). The top five threats that occur frequently and have a huge impact on the Hawaiian monk seal include food limitations, entanglement in marine debris, assorted human interactions (primarily in the MHI), habitat loss (possibly climate-related), and shark predation.

In this list of five threats, disease is not included because it is considered to occur less frequently and its impact as a threat to recovery of the species is minimal (NMFS, 2007). A basic understanding of disease exposure in the population is based on routine, ongoing epidemiological surveys, hematology, serology biochemistry, and parasite testing of live animals. Spatial differences in some parameters exist between sub-populations but are not considered clinically significant (NMFS, 2007; Aguirre, 2000; Reif et al., 2004). This type of data from FFS does not stand out as exceptional (NMFS, unpubl. data). Unusual mortality events have occurred: a die-off of at least 50 seals on Laysan Island in 1978 associated with ciguatoxin exposure, 4 aborted fetuses on Laysan in 2000, and a die-off of 11 seals across the NWHI in 2001 associated with malnutrition (NMFS, 2007; Gilmartin et al., 1980; Antonelis et al., 2001). No necropsied deaths of juveniles at FFS have been associated with ciguatoxin (NMFS, unpubl. data).

Individual subpopulations of monk seals show similar patterns in age-specific survival across the NWHI, except at FFS. Survival during the 5 to 6-week nursing period tends to be quite high (> 90%) at all NWHI subpopulations because of maternal attendance, protection and provisioning, and the existence of a few other threats to survival at this stage of life (Johanos et al., 1994). FFS stands out as an exception to this pattern (Baker, 2008). The number of incidents (severe bite wounds, suspicious disappearances and confirmed shark attacks) on preweaned and newly weaned pups totaled 198 at FFS, 8 at Laysan Island and 15 at Lisianski Island between 1990 and 2008 (Harting et al., in prep.).

Juvenile, subadult, and adult survival rates vary significantly over time, but general patterns are apparent (NMFS, 2007). Across the NWHI, the survivorship of seals aged from weaning to age 3 has declined most dramatically of all the age classes; their poor and declining condition as well as smaller body size given their age are consistent with signs of limited food resources (Baker, 2008). This situation may be a result of competition with other apex predators such as some shark species, other monk seals, less efficient foraging skills of young seals, and changes in ocean productivity reducing the availability of prey. At FFS, malnutrition and shark predation are responsible for poor juvenile survivorship, with the latter greatly affecting preweaned and recently weaned pup survival (Baker, 2008).

Reducing shark predation on seal pups is one of the four key activities identified in the Recovery Plan (NMFS, 2007). Recommended actions listed that are pertinent to shark predation mitigation are:

- Continue monitoring shark activity and predation events.
- Remove problem sharks.
- Develop general criteria (and site-specific plans) for shark removal.
- Refine methods for shark removal.
- Maintain needed permits for shark removal and/or other intervention.
- Be prepared to rapidly respond to predation events.
- Have trained staff and gear for intervention.
- Characterize trends in shark abundance, movement patterns, and predation losses throughout the NWHI in relation to these interventions, and conduct shark behavior research.

French Frigate Shoals: Shark Predation Contributes to A Unique and Extreme Situation

Among the six primary breeding sites in the NWHI, FFS has experienced the most precipitous decline based on beach counts and number of pups born generally falling from the 1980s through 2008 (Caretta et al., 2007; Caretta et al., in prep.) (Fig. 3).

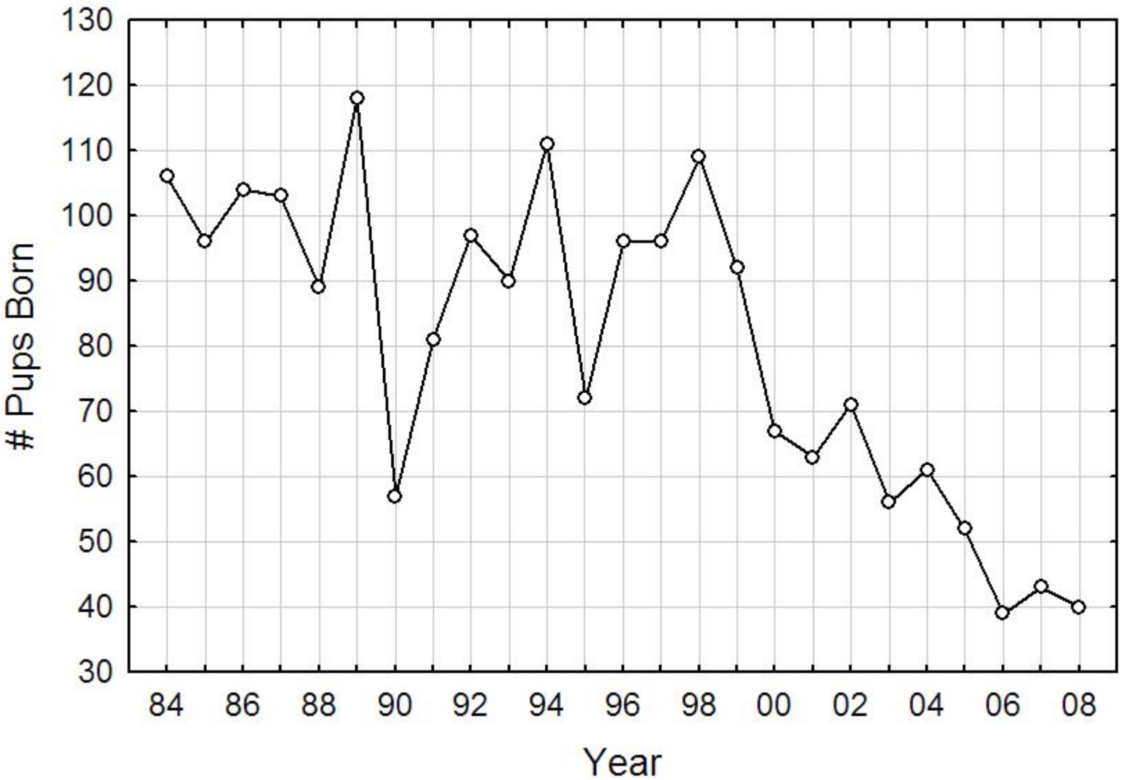

Figure 3.--Number of pups born at FFS between 1984 and 2008.

FFS was once the most populous site with more than 400 individuals residing there in the late 1980s; however, the estimated number in 2006 was only 189 seals (NMFS, unpubl. data). The primary factors in the FFS subpopulation's decline have been poor juvenile survival exacerbated by lower reproductive rates. Survival of preweaned and recently weaned pups to age 1 at FFS was historically higher than in recent years, declining from about 95% in the late 1980s to less than 75% in 7 of the last 8 years (Baker, 2008; Harting et al., in prep.). The prolonged period of low juvenile survival at FFS has produced an anomalous age structure. Many of the reproductive females at FFS are now at an advanced age and are entering the phase of reduced fecundity, with few younger females to replenish the breeding population. Consequently, the number of pups born at FFS has declined from approximately 120 in the late 1980s to only 34 in 2009 (NMFS, unpubl. data). Population projections using a dedicated stochastic simulation model predict a steady decline at FFS over the next 25 to 50 years based on an assumption that current demographic rates and conditions are representative of those that will occur over the lifetime period of the simulation (Harting, 2002).

Beginning in 1997, a marked increase in shark predation on preweaned monk seal pups at FFS occurred (Hawn, 2000; Hayes, 2002; NMFS, 2003; NMFS, 2004; NMFS, 2005) (Fig. 4). At Trig and Whaleskate Islands, the number of predation mortalities from sharks (including both confirmed and inferred losses, defined in Appendix C) peaked between 1997 and 1999. Additional pups were permanently maimed by severe shark bites that likely reduced the seals' ability to dive, forage and reproduce (Fig. 4).

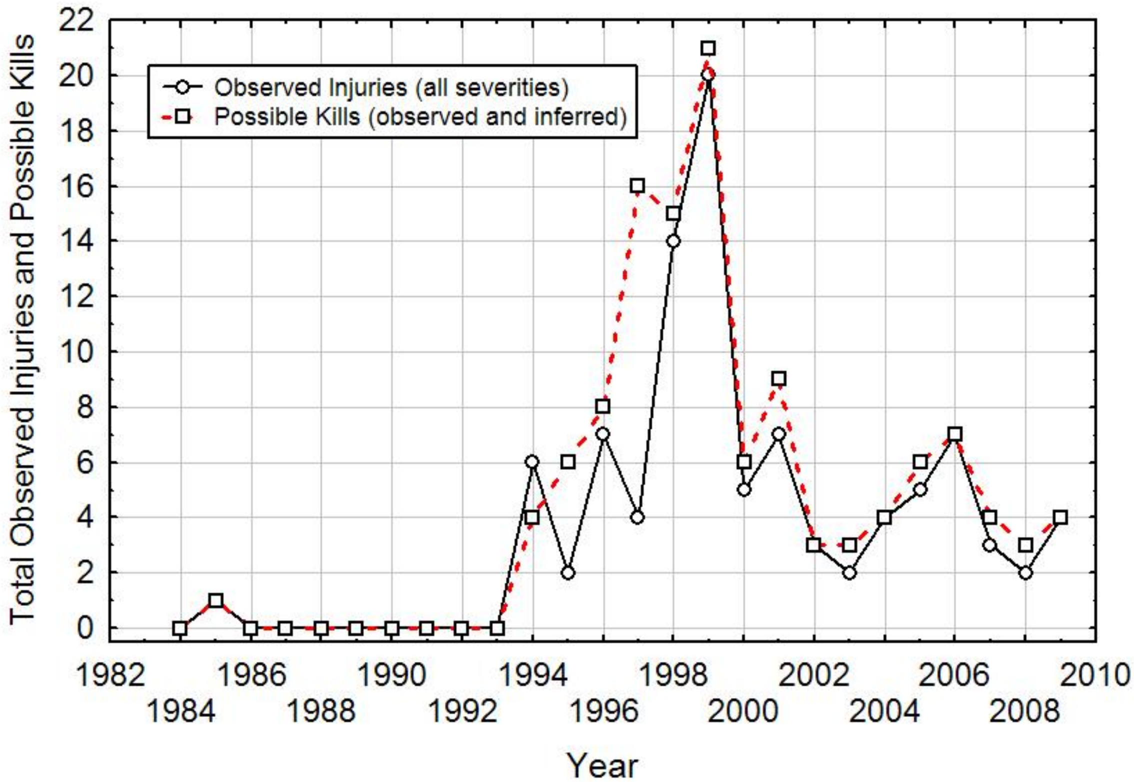

Figure 4.--Shark incidents on monk seal pups at FFS for the April 1—September 30 time period for years 1982 through 2009.

Subsequent to the period of peak loss, preweaned pup mortalities from sharks declined but remained at a level unsustainable for recovery goals (Harting et al., in prep). Between 2000 and 2009, the number of preweaned pup losses (confirmed and inferred) at FFS atoll-wide was at 6–11 pups per year. As fewer pups have been born each year for the last several years, the numbers of pups lost to predation has exacted an increasingly heavy toll. Since 2000, 15–28% of the incoming FFS cohort has been lost each year to shark predation. From 1997 through 2009, 205 of 835 pups born at FFS (24.6%) were involved in shark incidents (NMFS, unpubl. data).

Direct observation or confirmation of a shark attack is generally rare. The disappearance of a healthy pup (greater than a week old), which is not coincident with inclement weather/seas or aggressive male seal behavior, and whose mother is typically searching and vocalizing, is considered to be a shark-induced death (see Appendix C). The minimum age criterion of 1 week old is based on results from a behavioral study on 30 mother-pup pairs at FFS that demonstrated that only pups less than a week old died as a result of high seas/wave wash (Boness, 1990).

Periods of intensive observation have occurred over the last decade to confirm shark predation and identify the species involved. In 1998, a number of individually identified Galapagos sharks patrolled Trig Island repeatedly within the same season (NMFS, unpubl. data). A 12-foot observation tower was erected on Trig Island in 2000 to 2003 to better observe shark activity; 2683 observation hours recorded shark sightings, attempted attacks and incidents on pups in daylight hours (NMFS, 2003; NMFS, 2004; Harting et al., in prep.). Additional observations of shark activity were also recorded in 1997–1999 and 2004–2007.

Observed Trends in Shark Predation

R. Dean Grubbs and C. Meyer summarized information about Galapagos and tiger shark movement and behavior, especially at FFS, at Workshop II (detailed in Section I). The following provides additional information about the species' behavior at FFS.

Galapagos sharks have been implicated as monk seal pup predators as derived from direct observation; gut contents of tiger sharks containing seals of unknown age suggest their possible involvement. Galapagos sharks are the only shark species observed by HMRSP to be near pupping sites charging, chasing, biting and killing preweaned pups. (NMFS, 2003; NMFS, 2004; NMFS, 2005; NMFS, in prep.; Harting et al., in prep.; NMFS, unpubl. data). Based on tagging and other distinguishing features of individual sharks during the peak times of shark predation (1998), a minimum of 14 identified Galapagos sharks were observed patrolling or pursuing preweaned pups at Trig Islet (NMFS, 2009). One of the previously sighted and tagged Galapagos sharks from 1998 was again sighted around Trig Islet during the 1999 pupping season and was identified with the killing of a preweaned pup that year (Harting et al., in prep.).

Globally, Galapagos sharks are resident insular, typically found in depths of 150 m. They feed primarily on cephalopods, elasmobranchs, and reef, demersal and bottom fishes (Vatter, 2003). However, it has been reported that pinnipeds have been included in the Galapagos shark diet (Compagno, 1984). Shallow water predation by sharks, especially during dusk and nocturnal hours, has also been described in the literature (Castro, 1983). Results from insular shark surveys in the NWHI at 10 major shallow reefs (< 40 m) (2000–2002, 2004, 2006, 2008) indicate that Galapagos sharks are not commonly found in shallow areas (NMFS, 2009b). Together, these findings suggest preying on pinnipeds at shallow depths is not common but it is within the behavioral repertoire of the shark species.

Tiger sharks are opportunistic predators that consume a diverse array of taxa including marine mammals (Meyer et al., 2009). A clear ontogenetic shift in diet occurs in both increasing prey diversity and increasing prey size as shark size increases for Galapagos and tiger sharks (Wetherbee et al., 1996; Meyer et al., 2009). Gut contents of 3 tiger sharks out of 23 caught in 1977 at FFS contained monk seals of unknown age; no seal remains were found in the gut contents of the 2 Galapagos sharks caught (Taylor and Naftel, 1978). No seal remains were found in the gut contents of 4 tiger sharks and 11 Galapagos sharks caught in a 1998 study (Vatter, 2003).

Other trends noticed in shark predation patterns at FFS include: (1) a general decline from the 1997–1999 peak to 6–11 pups lost per year, (2) a shift in shark activity from centering around Trig and Whaleskate Islets to additional islets within the atoll (East, Gin and Round Islets) (Fig. 5), and (3) an increasing predation focus on the youngest pups (Fig. 6). The decline in shark predation and greater distribution of predation may be a result of a combination of any of the following factors: the disappearance of Whaleskate Islet (1998), the removal of 12 Galapagos sharks (from 2000 to 2006), a natural flux in shark population, the increase in researchers and activity, the translocation of weaned pups to Tern (beginning in earnest in 2001) and the fact that fewer pups are born compared to the past and, thus, fewer are available as prey at any one place and time (Harting et al., in prep.). An increase in the relative percentage of preweaned pup prey versus older pups may be a reflection of the translocation of weaned pups to safer islands (i.e., Tern, East). Seventy-three percent of pups confirmed to be attacked from 1997 to 2006 were estimated to be between 17 and 32 days old when they sustained a moderate to severe injury (NMFS, unpubl. data).

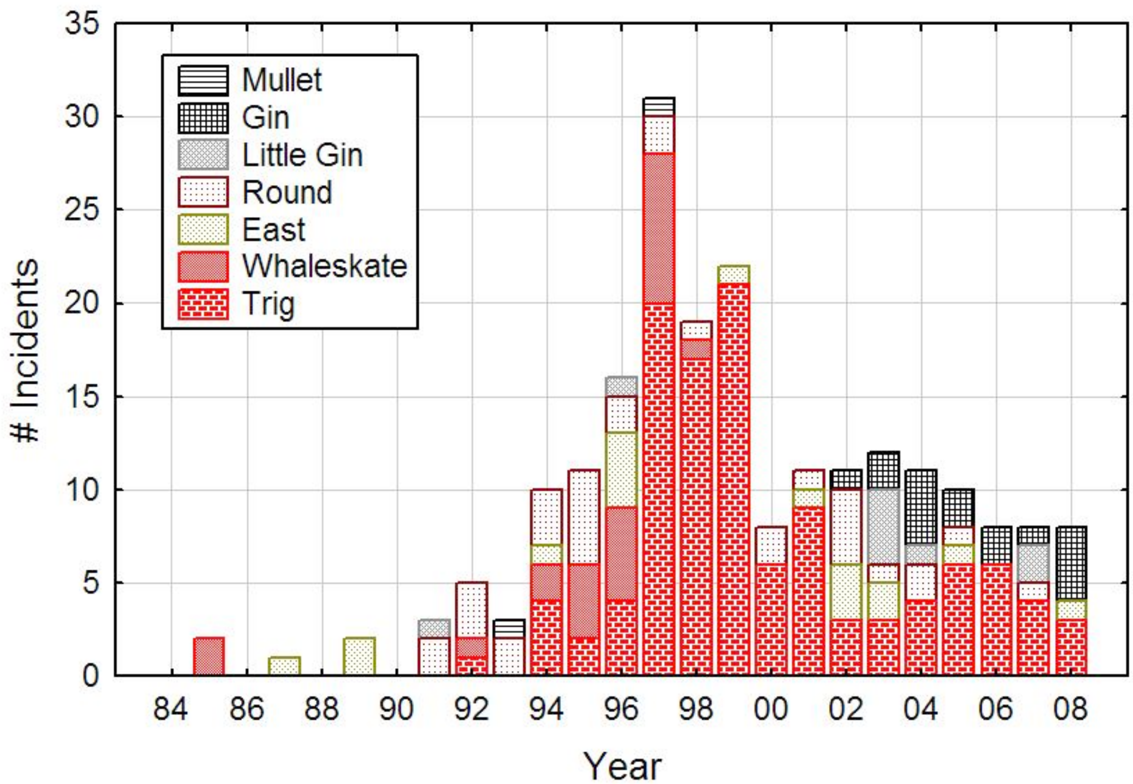

Figure 5.--Distribution of shark incidents across the islets of FFS Atoll from 1984 to 2008.

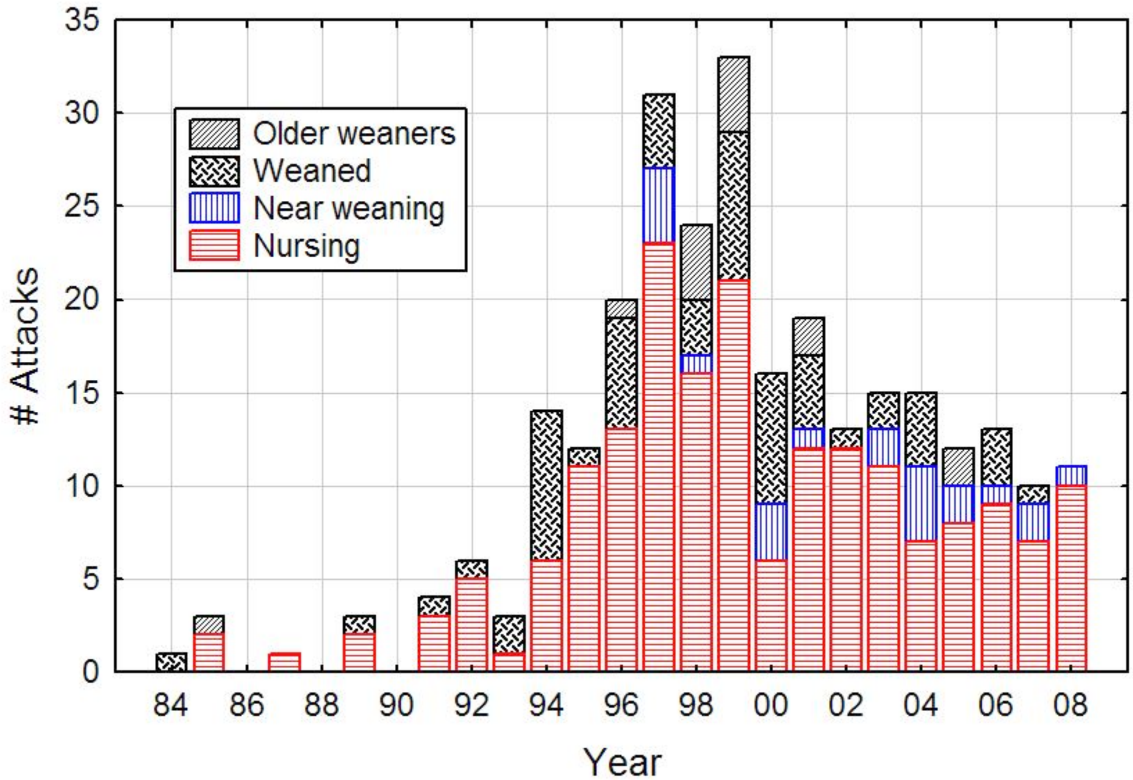

Figure 6.--Age classes of pups involved in shark incidents at FFS from 1984 through 2008. Older weaners are defined pups 30 days postweaning and older.

Significant Covariates of Shark Activity

An examination of possible factors influencing shark activity in 2000 at Trig Island was conducted (Hayes, 2002). Sample sizes (shark incidents) were small and a multivariate analysis was not conducted; thus, results presented here are suspect. Fourteen pup injuries, deaths, and disappearances were attributed to shark predation. Numerous Galapagos sharks were positively identified patrolling the beach and attacking pups; one tiger shark was positively identified to be present at Trig on 1 day only and to be associated with attacking a beached pilot whale. High numbers of pups seen on the beach significantly influenced shark predation rates, as shark incidents occurred more frequently when six or more pups were present. The largest sized sharks were significantly more aggressive toward monk seals than smaller sizes. After a shark-culling event, significantly fewer shark sightings occurred. The rate of shark predation events was significantly reduced after the sharks were harassed. Shark activity on the day prior and after an incident did not significantly increase. Moon phase and tide height were mentioned but not statistically examined.

An examination of possible factors influencing shark activity in 2001–2003 at Trig Island was conducted; data were collected from the observational tower on Trig Island. For 2001 to 2002 data, the number of mother-pup pairs was the only significant factor tested and it was only weakly positively related to shark density for all activities (from cruising to attacking) (R^2 = 0.0576, $p < 0.007$) and for predatory activities only (from patrolling to attacking) (R^2 = 0.0739,

$p < 0.003$) for 2001 and 2002 (NMFS, 2003). However, data were not normally distributed and should be viewed with caution. For the 2002 data, a Chi-square test indicated a significant relationship between pup density (less than 6 pups versus more than 6 pups) and attack versus no-attack days ($p = 0.0348$); a Fisher exact test was not significant ($p = 0.0614$) (NMFS, 2003). There was a significant increase in the rate of shark presence proximate to an incident (i.e. presence on the day of an attack or day after a night attack) (p=0.0487) (NMFS, 2003). Galapagos shark sighting rates did not significantly differ on fishing days (i.e., 12 days of attempted or successful removal of sharks) versus non-fishing days (paired *t*-test: $p = 0.0893$).

In general, shark behavior is highly individualistic and unpredictable over time. In 2000–2003 4 Galapagos sharks (size range 182–231 fork length) were tagged with acoustic transmitters near Trig Island in the months of June and July; CPUE was 0.015 sharks per hook hour (274 hours total). Based on 786 detection days for 3 of the sharks, the island they frequented most was Trig, their maximum distance ranged between 5 and 14 km, and their occurrence varied widely on both a daily and annual basis. Tiger sharks were rare around Trig, although 3 were caught in October of one of the years (after the pupping season) (Lowe et al., 2006).

Abundance of Galapagos Sharks at FFS

The population size of Galapagos sharks at FFS is difficult to determine; however, a likely range is determinable from recent research. DeCrosta (1984) estimated the population to be 703 individuals based on the area within the 30-m depth contour of the atoll. However, the Galapagos shark population may have grown since then as a result of an ecological release restricting longline fishing within the vicinity of FFS (Holzwarth et al., 2006). Based on data from towed-diver surveys conducted in 2000 through 2003 (Holzwarth et al., 2006), the population can be estimated at 4380 individuals (based on an area of 1540 km^2, 80% of shark biomass as Galapagos shark species, and average Galapagos shark weight of 0.15 metric tons). This is likely an overestimate because Galapagos sharks are attracted to towed divers (Parrish et al., 2008). Based on an ECOPATH model approach, the population is estimated at 1604 individuals.[1] A 2009 sonic tagging study of Galapagos and tiger sharks may be able to provide a crude population estimate as well in 2010.[2]

Observed Trends in Pup Behavior

A focal pair study, using scan sampling on a 15-minute interval documented typical monk seal mother-pup movement and behavior on East Island, FFS for 1987–1988 ($N = 52$ mother-pup pairs, 30 pairs were followed from birth to weaning) (Boness, 1990). The average distance between mother and pup was 0.2 m (2.6 SE) on land and 1.3 m (3.46 SE) in the water. Time spent in the water was 22.3% (8.32 SE) for mothers and 24.1% (6.86 SE) for pups. The number of transitions (leaving land to go into water) per day was 5.2 (2.13 SE) transitions for mothers

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[1] F. Parrish, NMFS PIFSC EOD, Honolulu, Hawaii. Pers. commun., March 2009.
[2] C. Meyer, HIMB, Coconut Island, Kaneohe, Hawaii. Pers. commun., September 2009.

and 5.6 (1.7 SE) transitions for pups. Pairs spent 97.1% of the time in coordinated movement and were asynchronous 1.8% of the time. Pairs were inactive for 89.9% of the time (e.g., resting or engaging in low-level activities such as vigilance, grooming, changing posture) and active for 10.1 % of the time (nursing, swimming, moving to and from the water or engaged in social interactions with other seals). In this study, 3 pups died in the first week of life, all attributable to high tides and surf (1 pup disappeared and 2 pups were separated from their mothers and remained abandoned).

General observations by HMSRP from the tower on Trig (2001 to 2004) in subsequent years mirrored Boness' findings. Pups remained within approximately 30 m of the shoreline throughout the nursing period, spent the majority of their time on the beach, and typically remained within a few meters of their mothers until weaning and became more precocial as they matured (NMFS, unpubl. data).

More than a Decade of Mitigation Activities

The HMSRP has implemented a wide variety of activities to curb shark predation on preweaned and newly weaned pups since the peak in pup losses in 1997. Avenues for reducing predation have included limiting predation opportunities by removing prey (pup translocation), preventing predation using deterrents such as devices or harassment, and removing predators (Fig. 7).

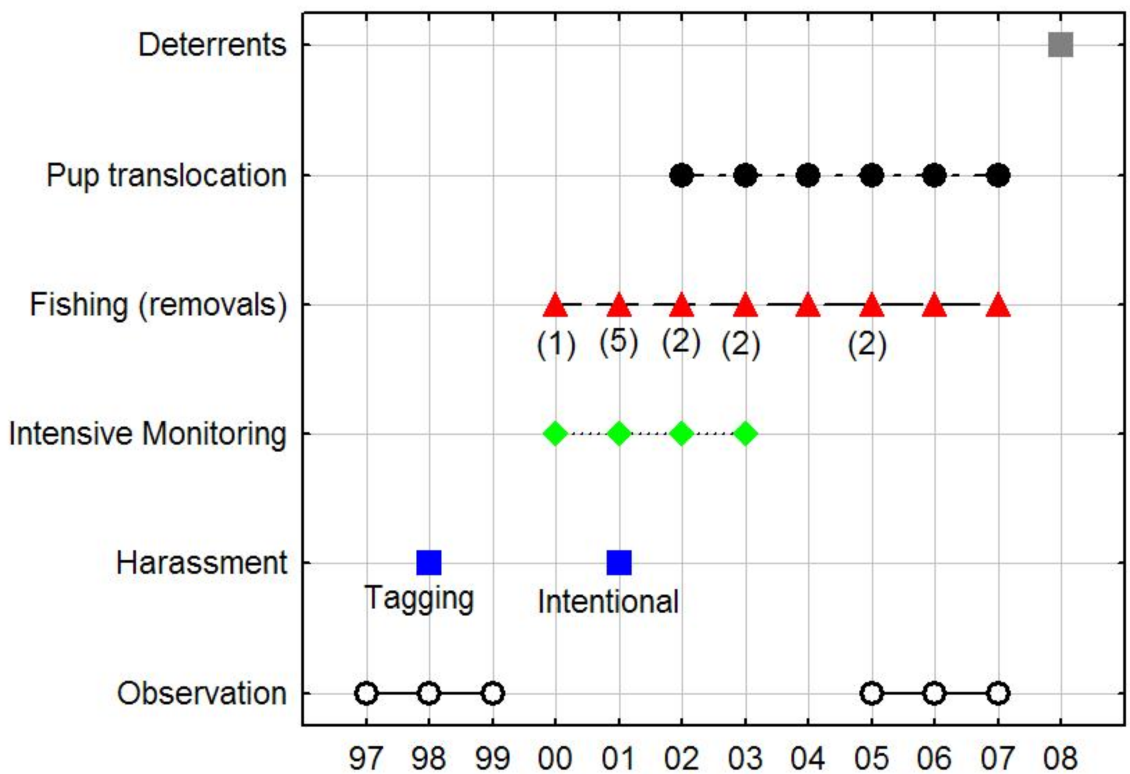

Figure 7.--Shark predation mitigation activities conducted by HMSRP from 1997 to 2008.

Since 2001, HMSRP translocated newly weaned pups from islets with intense shark activity to Gin, East, and Tern Islets. However, predation was later detected at Gin and East, so the majority of translocations continued to occur at Tern, an island with a historically low number of incidents (NMFS, unpubl. data). Translocating pups at the weaning stage represented the first available opportunity for moving them to safe areas so as to not disrupt the mother-pup bond and nursing interactions. Translocation removed weaned pups from the highest risk areas. As a result, pups remaining at unsafe sites (i.e., Trig Island) became the only available targets of shark predation by default. Thus, preweaned pups and newly weaned (within the first few hours of weaning) were not protected through translocation.

A trial of four deterrents and devices was conducted in 2008 and fully reviewed in Section I of this memorandum. In brief, ceramic magnets and electromagnetic deterrents (Shark Shields), as well as a visual device (moored boat) and auditory device (boat noise), were simultaneously deployed at Trig Island. Four shark incidents occurred on a cohort of 16 pups in 2008. The efficacy of these deterrents and devices to prevent shark predation was equivocal, in part, because of the low sample size and the study design but also to the fact that a few shark incidents did occur during the period that some of the deterrents and devices were operating.

In November 2008, the impact zones of two Shark Shields were tested at two locations approximately 3 miles offshore in Haleiwa, Hawaii on 4 free-ranging Galapagos sharks. Sharks were first baited in with fresh squid, and feeding behavior was observed. After approximately 5 minutes, a Shark Shield was deployed from the side of a small 17-foot boat in the vicinity of the bait. Galapagos sharks continued to feed and appeared to be deterred at a distance of approximately 1 m; they either avoided (quick turn away) or did not approach the bait in the 1 m zone. This diminished impact zone as compared to the manufacturer's claims suggests that the units function as a point deterrent rather than an area deterrent and are likely not effective across the large areas.

Intensive hazing and harassing of Galapagos sharks to deter them from pupping sites, especially Trig Islet, was implemented in 1998 (in the form of spaghetti tagging) and 2001 through 2004 (intentional harassment) (NMFS, 2003; NMFS, 2004; NMFS, 2005; NMFS, unpubl. data). The rate of shark predation events was significantly reduced after harassment events were initiated in 2001. Small sample sizes and the exclusion of significant covariates (i.e., pup density and shark culling) in this analysis should be considered in the interpretation of this result (Hayes, 2002).

Small-scale culling operations to remove Galapagos sharks were initiated in 2000 and continued each year thereafter until 2007. A total of 12 Galapagos sharks were removed from 2000 to 2006 (1 shark in 2000, 5 sharks in 2002, 2 sharks each in 2003, 2004 and 2006; no sharks were removed in 2001, 2005 and 2007) (Hawn, 2000; Hayes, 2002; NMFS, 2003; NMFS, 2004; NMFS, 2005; Harting et al., in prep.). Methods included harpooning and fishing with handlines and drumlines in shallow waters primarily near Trig. CPUE was exceedingly low and appeared to decrease each successive season (NMFS, unpubl. data). In July and October 1999, more than 50 Galapagos sharks were removed from FFS by commercial fishers, partially operating in the deep lagoonal area of the atoll (NMFS, unpubl. data; Vatter, 2003). These 1999 removals and the 2000 removal of 1 Galapagos shark by HMSRP was associated with the greatest drop in preweaned pup losses to shark predation to date, from 22 pups killed in 1999 to 8 pups killed in 2000 (Fig. 4).

SECTION III. HAWAIIAN MONK SEAL RESEARCH PROGRAM POST-WORKSHOP DEVELOPMENTS

Shark predation mitigation may be a relatively manageable problem compared to other actions that are crucial to the recovery of the Hawaiian monk seal as prescribed in the Recovery Plan. For example, food limitation and entanglement potential are ubiquitous problems and require a huge annual effort across the entire archipelago to mitigate, whereas shark predation on preweaned and newly weaned pups is primarily a problem at one location, FFS. As such, there may be a real benefit to focusing resources to mitigate this threat and protect additional 6–11 pups a year at FFS.

A Small Number of Site-specific Galapagos Sharks

HMSRP's central hypothesis, based on data gathered to date and with the support of several experts familiar with this predator-prey system at FFS, is that a small number of site-specific Galapagos sharks is likely involved in pup predation. This notion was formed, in part, by the distinctiveness of this behavior for the species and the apparent low numbers of Galapagos sharks in the atoll reflected by low CPUE and rarity of sightings during the intensive observation period in 2001–2004. However, the opinion has been voiced that this "small subset hypothesis" may now be more difficult to test because of possible changes in the context of predation. Changes made as a result of expending time in shark predation activities, for example, may have resulted from HMSRP's succession of attempts to remove and deter sharks and any corresponding alterations in shark behavior in response to these attempts.

A predation mitigation focus on Galapagos sharks is consistent with HMSRP's experience and data and analysis to date (NMFS, 2003; NMFS, 2004; NMFS, 2005; NMFS, 2008; Harting et al., in prep.). All actions executed in the 2009 field season that aimed to detect, deter, and collect information on movement and behavior did not discriminate by shark species. Preliminary analysis of HMSRP's 2009 data confirms Galapagos shark involvement again. HMSRP currently has no data to substantiate predation of preweaned and newly weaned pups by tiger sharks. No confirmatory evidence (direct observations and video footage viewed to date) of tiger shark involvement is apparent yet in the 2009 data. Even with this information, tiger sharks involvement cannot be categorically excluded and should be investigated given the catholic diet and nocturnal predatory behavior of the species.

Opportunities to continue to detect tiger shark predation and to further understand their movement and behavior patterns should be a part of shark research and mitigation plans going forward. However, it may not be prudent at this time to attempt to manage the interactions of shark species with preweaned and newly weaned pups other than Galapagos sharks.

Wariness of Sharks to Humans

HMSRP also hypothesizes that Galapagos sharks in FFS are wary of humans. A decrease in CPUE and sightings over time without a coincident drop in incidents support this notion. Fishing efficiency (removals per effort hours) progressively deteriorated throughout the 2000–2006 fishing period, when number of hook hours ranged from 10 to 30 hours per season (Harting et al., in prep.). The sighting rate of Galapagos sharks during the 2001–2004 intensive tower observation period had declined over time, but the total number of incidents (confirmed and inferred attacks) did not decline and the number of inferred attacks increased. This suggests that shark wariness of humans and/or the tower may have contributed to a decrease in day predation and an increase in crepuscular and night predation (when observation of attacks is not possible). Also, there is no history of shark incidents on preweaned or newly weaned pups at Tern, where researchers and USFWS staff reside in a large compound (NMFS, 2003; NMFS, 2004; NMFS, 2005; NMFS, 2008; Harting et al., in prep.). A report on shark densities and their proximity to human population centers showed a highly significant negative relationship between grey reef and Galapagos shark densities and proximity to human population centers. High numbers of sharks were prevalent around islands with no human habitation but within reach of populated areas at only 15–40% of the population densities around the most isolated near-pristine reefs (NMFS, 2009b).

The "human wariness" premise warrants more investigation because human presence may be a useful shark deterrent itself, as suggested at Workshop II. On the other hand, human presence may also hamper the effectiveness of some fishing methods. For example, fishing techniques requiring constant attention or maintenance by fishermen may lead to lower catch rates.

Predatory Behavior

A third premise of HMSRP is that any Galapagos sharks sighted in the nearshore areas of pupping sites (within 50 m of shore given that preweaned pups will range up to 30 m from land with their mothers) are potential predators of monk seal pups. Galapagos sharks frequent deeper waters and are rarely found in shallow waters in FFS as demonstrated by the CPUE across the atoll (see Sections I and II). The majority of Galapagos sharks sighted near Trig and Gin Islands when pups were present demonstrated predatory behavior (patrolling, lunging, chasing and attacking pups) and pursued pups in water as shallow as the wave wash (NMFS, 2003; NMFS, 2004; NMFS, 2005; NMFS, unpubl. data). Circling out from deeper water into the wave wash is a frequent pattern of the movement of Galapagos sharks observed prior to attack (NMFS, unpubl. data). Video footage demonstrates that some individuals circled repeatedly for 20 minutes to 2 hours prior to or between attack attempts (NMFS, unpubl. data).

Shark Culling

Removing a limited number of Galapagos sharks to mitigate this source of seal mortality likely facilitates the maintenance of biodiversity at this atoll overall. As an endangered genus, Hawaiian monk seals hold a prominent place among this biodiversity. Monk seals are at risk of going extinct at FFS, in part, driven by some number of Galapagos sharks that prey on pups. It is regrettable to consider removing a limited number of sharks permanently; as an apex predator, they are also a valuable part of the system. However, the removal of preweaned and newly weaned pups from shark predation year after year is unsustainable. The low recruitment of female monk seals reaching into adulthood, especially at FFS, is a crisis for the species. The death of female preweaned pups as a result of shark predation exacerbates this endeavor greatly.

Annual or biannual surveys of insular shark densities suggest that shallow (< 40 m) inshore water shark populations appear to be relatively abundant at most reefs in the NWHI and Pacific Remote Island Areas (NMFS, 2009 draft report to Congress). CPUE from shark tagging studies in the waters surrounding FFS mirror this finding (Lowe et al., 2006; C. Meyer, unpubl. data). On balance, the removal of 10–40 Galapagos sharks to reduce the loss of approximately 20% of the monk seal annual cohort is appropriate to retain the greatest diversity of the Monument's wildlife resources into the future. Removal methods of sharks would have a minimal impact on the physical environment and other species and if an adaptive management approach is taken, then HMSRP believes that limited shark culling near pupping sites is reasonable and sensible.

Post-Workshop Developments

Post-workshop, HMSRP systematically compared all proposed mitigation actions by detailing the potential benefits and drawbacks of each based on more than 20 years of experience with the species in the field. Program scientists voiced details about each potential mitigation action here that were not discussed at Workshop II because of time constraints. All available sources of knowledge, Workshops I and II testimony and recommendations, peer-reviewed science, HMSRP's first-hand experiences, expert opinion and inference make up a pro-con list provided at Appendix D and the following plans and developed ideas.

Plans executed in 2009 include:

- Continued translocation of newly weaned pups as soon as possible from Trig and Gin to Tern Island.
- Logistical and financial support for HIMB shark scientists to conduct shark tagging studies at FFS.
- Design and installation of a custom-made remote surveillance camera system at one pupping site.
- Systematic application and comparison of 3 treatments on 2 pupping sites: human presence, devices that function as human proxies and a control.
- Initiation of a behavioral study to examine monk seal pup nocturnal behavior and swimming distances from 2 pupping sites.
- Creation of a standardized shark sighting/attack/incident form and initiation of analysis of past shark sighting data.
- Initiation of a pup tagging study to detect coincident movement with tagged sharks.
- Initiation of individualized deterrent testing on free-swimming Galapagos sharks in main Hawaiian Island waters. (See Section II for Shark Shield effective range results.)

Plans developed but not executed in 2009 include:
- Creation of a protocol for the limited removal of Galapagos sharks in the vicinity of pupping sites.
- Creation of a protocol for the expanded removal of Galapagos sharks at FFS.
- Collection of preliminary information on barrier design.

Actions Taken in 2009: Translocations, Shark Tagging, Remote Camera Installation, Seal and Shark Behavior Studies, Comparison of Deterrent Treatments

The number of pups born at FFS this season was the lowest on record at just 31 individuals (as of August 19, 2009). Field staff directly observed sharks patrolling pup sites on 13 different days, 3 of which concluded in attacks. In all, 4 pups suffered shark bites, of which 2 subsequently died within a few weeks. The remaining 2 are not expected to survive long based on the severity of their wounds. An additional 5 pups disappeared, 3 of which can be inferred as shark caused.

Translocations of newly weaned pups continued with 14 pups moved from Trig, Gin, Round, and East to Tern Island. HMSRP deems translocation a valuable tool in boosting pup survivorship and recommends its continuance. Preweaned pups are a primary target of sharks but not candidates for translocation because their nursing and bonding requirements preclude action by HMSRP to move them to safer areas. Thus, additional actions that protect younger pups are required.

Several of the actions executed in 2009 aim to inform the “small subset” premise. First, the acoustic tagging study lead by Carl Meyer (HIMB) aimed to tag Galapagos sharks across the three habitat types to determine their movement across the atoll for the life of the tags (approximately 2 years). One hundred and eighty-nine sets were made with 1570 hooks yielding 6850 hook hours; 68 Galapagos sharks and 40 tiger sharks were sonic tagged between May and August 2009. Additional sharks were spaghetti tagged. Analysis of this data will help determine the percentage of tagged sharks that frequent the pupping sites when pups are present. Partial-analysis is expected to be available in 2010 and a more complete analysis in 2011.

Second, a remote camera system was installed at Trig Island by HMSRP to capture shark activity in the sector (2E) that showed the most nursing pups on the beach and shark activity in the nearshore water. The estimated visual range of the cameras was a maximum of 120 m in optimal light conditions to the south and east (sand beams blocked views to the west). Analysis of video footage will help determine shark species, frequency of visits, and times (between 0530 and 1900 hours) of greatest activity. Video viewing and cataloguing of data are currently under way. Video footage viewed of data reveals additional Galapagos shark sightings and attacks on pups.

Third, field staff camped on Trig and Gin Islands for several weeks across the season to directly observe and systematically record shark behavior, mother-pup-shark interactions and mother-pup behavior at night (Appendix F). These data will also help determine shark species, frequency of visits and activity times, as well as the responses of seals to shark presence, the typical distances that mother-pup pairs venture into nearshore waters, and the frequency that mother-pup pairs enter the water in the night. Data from these observations are currently being entered into a database.

A field study was conducted in 2009 to inform the "human wariness" premise. Three treatments: human presence, devices that function as human proxies and a control were alternated weekly on 2 pupping sites, Trig and Gin Islands across the field season. Treatments are defined in Appendix E. Preliminary analysis indicates that the probability of an incident occurring (confirmed attack, wounding and disappearance) is not significantly different by treatment. The number of incidents totaled 7; low sample size may have precipitated this nonsignificant treatment effect. Video footage from randomly chosen days across treatments will be viewed, and shark sightings and attempted attacks will be recorded. This additional data will supplement the number of incidents across treatments at Trig Island, boosting sample size for a more robust analysis that is expected to be available in 2010.

Behavioral observation of pups at night and sonic tagging of newly weaned pups were conducted to collect information on pup movement and behavior. For a review of basic mother-pup behavior, see Section 2. Shark-inferred disappearances are commonly discovered during morning patrols. At Workshop II, there was a discussion about the frequency with which pups enter the water at night, how far they swim offshore and if their disappearances could be caused by something other than predation. Pup behavior was systematically recorded in 2-hour time blocks from dusk until 0400 hours to help answer these questions. Data from these observations are currently being entered into a database.

To track pup movement in the water and close proximity to patrolling sharks, sonic tagging was recommended. Current permits do not allow HMSRP to place instruments on preweaned pups. As a first step to determine the utility of this approach to gather pup-shark data, 11 weaned pups were sonic tagged. One subsequently died (not shark-related) and 6 were moved to Nihoa as a part of a different study. Signals from the remaining 4 pups will be examined along with signals from the 108 sharks tagged to investigate coincident movement of the 2 species over the life of the tags (battery life is dependent on tag size and is approximately 6 months).

Ideas Discussed for the Future: Shark Removals and Barriers

HMSRP reinitiated thinking on limited and expanded shark removal as a potential predation mitigation option for the future. Discussion of shark removal ideas with Hawaiian cultural representatives and State and USFWS authorities occurred in April 2009. Protocols on limited and expanded Galapagos shark removal was created for a Programmatic Environmental Assessment and are included here as Appendices G and H. These protocols serve as a starting point for future discussions on this controversial action. A comprehensive discussion of the costs and benefits of shark removal is presented in Harting et al., in press.

HMSRP discussed the possibilities of designing shark barriers and their engineering challenges; however, the development or testing of these plans has not occurred. A preliminary design was drafted as a starting point for future discussions on this controversial action. (See Appendix I.)

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*Not invited or contacted formally, but should be aware of the workshop through their own agency contacts.

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APPENDIX B: 2009 HIMB SHARK TAGGING RESEARCH DESIGN, AS PROVIDED BY CARL MEYER, PHD

The overall shark-tagging plan at FFS is to put relatively even amounts of fishing effort into shallow lagoonal areas, deeper lagoonal areas and outside the barrier reef. To date, some tagging effort has been applied to all three broad habitat categories defined as: (1) shallow lagoonal (SL): 0–10 m depth, with focus on habitat close to pupping islands, (2) deep lagoonal (DL): 11–30 m depth, a minimum of several km away from pupping islands but still within the lagoon, and (3) outside barrier reef (OB): maximum 100 m depth, with most effort occurring > 30 m depth.

The CPUE is so low in the shallow habitats that massive amounts of fishing effort will likely be required to catch even a couple of Galapagos sharks in these areas. The shark team will be consistently setting a 5- or 10-hook line in these shallow habitats (Fig. 3, hook hours by habitat stratum graph). This constitutes a huge fishing effort in these shallow areas. At the same time the shark team will be maintaining effort in deeper areas of the lagoon and outside the barrier reef to ensure that a large number of Galapagos and tiger sharks are tagged. The position, soak-time and catch from all longline sets will be recorded so the distribution of effort can be assessed in a spatially explicit manner (Fig. 8). There are some practical limitations. For example, it is impractical to put huge amounts of fishing effort in around the Gins because of the distance from Tern, but effort will be put in around all major pupping sites. Also, fishing must occur on clean sandy ground, and not all habitats meet this description.

At least 18 receivers (each with a 15-month battery life) will be deployed at FFS by seasons end (August 15, 2009). We will download them at the end of the FFS trip and then in summer of 2010. If logistics allow, we will try to obtain additional downloads in the interim. The aim is to create necklaces of receivers around key pupping sites (Trig, Round, Gins) in addition to our broad but sparse coverage of the rest of the atoll. Detecting any transmitter-equipped sharks that venture into the shallows around those sites where pup predation is suspected to occur is the goal; 5–10 receivers at each site will help ensure this goal is reached. In addition, a number of receivers are located outside of the barrier reef north and south of the atoll plus single receivers at Trig, Tern, Round, Gins, and La Perouse (deployed in 2008). This spread will provide insights into the broad scale movements of tagged animals at FFS.

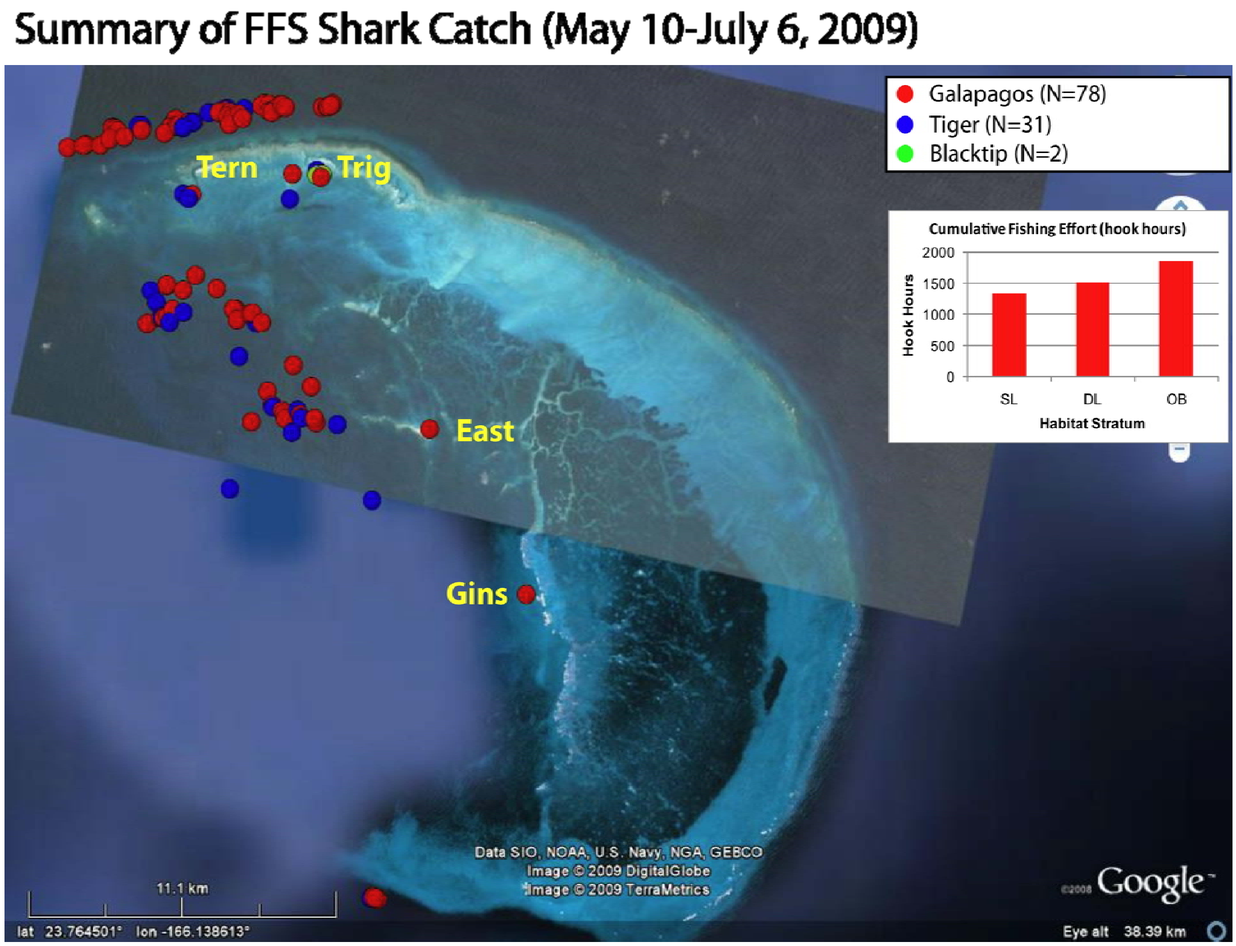

Figure 8.--Preliminary results of tagging effort: locations of shark captures by HIMB (red points are Galapagos sharks, blue points are tiger sharks) from May 10 to July 6, 2009; sharks were tagged with sonic and/or spaghetti tags. Tagging effort continued until August 15, 2009. For habitat stratum in the Cumulative Fishing Effort graph, SL is shallow lagoon, DL is deep lagoon and OB is outside breaking reef.

APPENDIX C: CRITERIA FOR AND CATEGORIZATION OF SHARK PREDATION OF MONK SEAL PUPS

Shark ***Confirmed*** Predation:

Injured by Shark: A pup of the year sustains an injury inflicted by a large shark of any severity and "survives" or does not fall into the dead or probably dead categories below. Here, large sharks are defined as all sharks other than the cookie-cutter shark (*Isistius brasiliensis*). These injuries include shallow punctures or lacerations in the skin, deep lacerations, gaping wounds, and amputated limbs. The characteristic crescent shape of these wounds reflects the shape of the shark's jaw (Hiruki et al.,1993).

Died due to Shark Injury: Confirmed deaths only (the death or body of the pup is observed). A pup of the year is observed being killed by sharks or the pup sustains moderate to severe shark injuries and subsequently dies. To be considered a cause of death, an injury must, at minimum, be of the following severity: the total combined exposed area of all gaping injuries to the body must be ≥ 8 cm (approximately 50 cm^2), ≥ ½ flipper is amputated, and/or injury to the head/eye results in a totally opaque/blinded eye. Shark attack will be judged to be the primary cause of death if the seal is not otherwise compromised to a larger degree based on factors such as preexisting emaciation or injury from other causes (HMS Field Manual, Survival Factor Section).

Disappeared/Probable Death due to Shark Injury: A pup of the year sustains a moderate to severe shark injury, subsequently disappears, and is classified as a probable death. Shark attack will be judged to be the primary cause of the disappearance if the seal is not otherwise compromised to a larger degree based on factors such as preexisting emaciation or injury from other causes. To be classified as a probable death, the minimum sustained injury must be of the severity level described above, and one of the following conditions must also be satisfied:

- The pup is lethargic, has trouble moving, and/or floating listlessly in the water and disappears for more than a week before the end of data collections***, OR***
- The pup is in deteriorating condition (loss of weight, enlargement of abscesses, sloughing skin) and it disappears for at least 10 surveys or a month prior to the end of data collection (whichever is longer).

Shark ***Inferred*** Predation:

Disappeared/Probable Death—Shark Inferred: Young, apparently healthy pups are also considered to have probably died if they disappear within 3 weeks of birth (> 7 days old and ≤ 21 days old) and are not seen for at least 10 surveys or a month prior to the end of data collection. Unknown-age pups are also included in this category if they were unmolted at the time of disappearance. The cause of these probable deaths is not known with certainty but considered shark inferred if: the pup is more than 7 days old, predatory shark behavior has targeted nursing/newly weaned pups in the current year and at that location, and there is no other probable cause. The pup's mother is typically observed to be in good condition, with a single pup, and is parenting normally prior to disappearance and often searching for her pup at the time of disappearance. Other probable causes of disappearances must be ruled out for a shark-inferred mortality to be concluded: aggressive adult male monk seals, extreme environmental conditions, and maternal abandonment. Adult male monk seals may injure weaned pups and inflict mounting injuries that are distinguished by distinctive scars and lacerations (Hiruki et al., 1993). Adult female seals (mothers) vigorously defend their pups from adult males during the nursing period (Johanos et al., 1994). Thus, preweaned pups are typically not vulnerable to male aggression. Unless a flagrantly aggressive male is observed at a pupping site within the current year, preweaned pup disappearance in the historical data is safely attributed to shark predation unless other compromising factors are present, such as extreme environmental conditions. Extreme environmental conditions, including high tides and/or strong currents, are considered a factor in pup disappearance primarily for islets that would go awash at extreme high tides, e.g., Round, Mullet, Bare, Disappearing, and potentially Whaleskate and Shark.

Suspicious Disappearance/Likely Dead—Shark Inferred: Slightly older, apparently healthy pups that disappear while still with their mothers or newly weaned seals are considered to have suspiciously disappeared and to be likely dead if they are not seen for at least 10 surveys or a month prior to the end of data collection. Pups in this category are more than 21 days old at the time of disappearance (or molting/molted if of unknown age), with a cutoff age of 2 weeks postweaning. Pups that are more than 2 weeks postweaning are not included in any shark-inferred category. The cause of these suspicious disappearances is not known with certainty but considered shark inferred if there is no other probable cause (see discussion above about probable cause above).

APPENDIX D: WORKSHOP II MITIGATION SUGGESTIONS: PROS AND CONS

Workshop II Ideas	Workshop Ratings		HMSRP Post-Workshop Discussion	
	Effect	Priority	Pros	Cons
Nonlethal Approaches				
Anchored boat	High	High	Low cost	Habituation issue/few ways of 'varying' signal
			Low maintenance	Unsure if effective although rated high
				Habituation-few places to safely move boat
Auditory deterrent	Med	High	Low cost	Habituation issue/few ways of 'varying' signal
			Low maintenance	Unsure if effective though rated medium
Shark Shields	High	High	"Barrier" with minimal entanglement risk	Expensive
			Lowered incidence of attacks occurred	Difficult to discern impact zone
				If custom array, impact on seals and turtles unknown
				High maintenance
				Recent tests demonstrate ineffectiveness
				1 m impact zone only
Barriers with Shark Shields	High	High	Likable	Entanglement hazard
			Unlikely to result in habituation	Maintenance high
				Requires a lot of development
				May prevent free access to other species
				Habitat impacts
				Some configuration may impede seals from a fast get-away
				Annual effort required
Active harassment	High	High	Human presence may be effective [2009 research suggests otherwise]	High staff needs, dangerous
			Potential to document attacks, reduce inferred losses	Temporary fix only
			Potential to intervene in attacks as they occur?	Impacts other duties for field camps
				Prolonged effort required
				Effectiveness questionable
Stratified deterrents	N/A	Med	Teases apart deterrent effectiveness	May show nothing b/c small sample sizes
			Increases coverage, may save more pups	Requires many sets of boats, speakers, shields
				Topography may prevent ideal stratification
				Not feasible on Gins

Weaned pup translocation			Protects pups well	Unsuitable for preweaned/nursing pups
Lethal Approaches				
Limited shark removal	N/A	High	Reduces threat if small subject involved	Bait, fuel, staff costs high
			Fishing may remove problem permanently	Low CPUE
				Methods used in past not ideal
				Public's concerns
				Opportunistic at best
				More difficult than expanded removal
				Unlikely to be successful at pup site
				Sharks, if tagged, more useful alive
Expanded shark removal			Reduces threat if small subset involved	Bait, fuel, staff costs high
			Repeat of C. Meyer's methods if successful	Bycatch issues-consult C. Meyer [2009-Meyer did not catch nearshore sharks]
				Public's concerns
Data Collection				
Remote camera system	N/A	High	Build upon green turtle methods @ East	Post's impacts need to be considered
			Reduces staff demand	Night observation difficult even with thermal-imaging
			Removes human presence which may confound	Any recording iinterval limits info
			If same as tower height, doable	Visibility during day-glare issues
Tag preweaned pups*	N/A	High	Bosters 'inferred shark kill' category if	Requires special permission
			Coincident movement with tagged sharks detectable	Tags likely easily lost (baby fur/molt)
			Pup handling not required	Low resolution data-depends on # of receivers
			Attempts to satisfy Workshop's concerns	Critics may say too inferential yet
				Difficult to interpret results
				Data on time in water not obtained
				General skeptics by some
Other Long-term Ideas				
Mom relocation, pre-pupping	N/A	N/A		NOT 2009
				Risky to adult females
				I'd. 'bad moms'-inaccurate due to data limits
				Special permission needed
				Pup loss may be situational
				Reduces reproductive potential for atoll if females are removed
				Demographic impacts for

				receiving site
				Logistics complexity
Mom-Pup pair translocation	N/A	N/A		Pup abandonment-Care facility required first
				Boosts density, risks ‘safe island’
Mom-Pup protection	N/A	N/A		Could unduly stress mother or pup
				Labor intensive to maintain
				Similar concerns as barriers above
Restore Whaleskate	N/A	N/A	Keeps FFS seals in atoll	NOT 2009, not for 5 years
				Moms may not pup here
				Sharks may attack here if designed poorly
				Army Corps required
				Process may be destructive
				Sea-level rise may negate any restoration
				Few moms at WS in ‘80s
				Potential negative impacts on atoll

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APPENDIX E: 2009 HMSRP SHARK DETERRENT PROTOCOL

The objective of this protocol is to test the hypothesis that human presence and/or human proxies (i.e., devices intended to deter shark predation) will lessen the frequency of shark presence and incidents. Three treatments: human presence, human proxies and control treatments (see definitions below) will be applied to 2 pupping sites, Trig and Gin Islets. The 3 treatments are meant to be mutually exclusive, and each treatment will be applied for 7 successive days (equals one session) and rotate on a continual basis. Treatments should start at each islet once pups are present and continue until feasible. The following variables may confound the statistical analysis of the effect of each treatment on shark presence and/or shark incidents on preweaned and newly weaned pups: the number of pups born, the birth dates of pups, low number of shark incidents, limited vision at night (of the camera and of observers) and the limited viewing field of the remote camera system.

Treatment Definitions

(1) Human presence treatment: overnight camping, activity, observation and fishing patrols (if permitted) for 7 consecutive days (6–7 night stays):

One to two people will camp on the island, providing a "near-constant" human presence throughout the treatment period. At least one human should stay on the island for at least 20 out of 24 hours per day. Absences during the treatment should total < 4 hours per day. Duration of absences should be recorded in a binder. Campers should strive to be active and consistent in their level of activity, e.g., 2–5 patrols (including population assessment as needed), 1–2 nearshore swims, 1–2 periods of movement around camp per day.

Behavioral observation of pups will occur during this treatment when possible (Appendix F). This activity is of low priority but should be attempted when the opportunity arises. Nocturnal behavior of pups will be observed with a night vision scope; observation session initiation will be staggered. Daytime behavior of pups will be observed to record water entries and approximate distance form shore when in water. Shark sightings and interactions with pups will be recorded if observed during any treatment when from the ground or a boat.

(2) Human proxy treatment (previously known as deterrents): devices deployed to simulate human presence, with a remote camera viewing system installed to record shark presence around deterrent array and near pups during the treatment.

Devices will be placed and moved to be near the majority of mother-pup pairs to have the greatest potential of protecting pups. However, placement and operation should be also consistent between proxy treatment cycles at each island. A boat (Livingston) will be moored at Trig located in shallow water near the majority of mother-pup pairs. If possible, 2 moorings will be created so that the boat's position can be shifted every 2 days. If possible, the boat should be positioned within either camera's view. At Trig and Gin, 2 speakers will be strategically placed in the vicinity of mother-pup pairs. Each speaker will have its own dedicated amplifier, MP3 player and timer, and sound output will occur 24/7 on a random repeat playing mode. Sound will be < 180 dB with varied recordings of boat-type noises that are in the upper range of sharks' hearing. The power source for the speakers will be on island, likely in a fixed position with little movement throughout the season. This will influence the placement/movement of the speakers through the field season. If possible, the speakers should be positioned within either camera's view. Staff visits will be limited to less than an hour per day for population assessment/beach counts, as required to gather important data not discernible from remote viewing of camera recordings. However, the frequency of such trips will be held to the minimum as necessary to accomplish high priority tasks that cannot be deferred until after the treatment period.

(3) Control treatment: minimal human presence/no proxies remote-camera viewing system only.

Humans and human proxies will be minimized at the island during this treatment. The remote camera system will record shark presence and activity during this treatment. Staff visits will be limited to less than 1 hour per day for population assessment/beach counts, as required to gather important data not discernible from remote viewing of camera recordings. However, the frequency of such trips will be held to the minimum as necessary to accomplish high priority tasks that cannot be deferred until after the treatment period. Proxy devices will be stored in a pallet tub on the island and the moored boat will be pulled into the center of Trig during this treatment.

APPENDIX F: 2009 BEHAVIORAL OBSERVATIONS ON SEALS AND SHARKS

The research objectives of the behavioral observation protocol conducted in the 2009 field season are based on Workshop II recommendations and include:

- Confirm that pups are located in nearshore areas when in the water, and derive average and maximum distances from shore across development.
- Determine if attendant mothers attempt to deter sharks while in the water and if this changes as pup matures.
- Document the behavioral context/factors that lead to mother/pup separation or force pups into the water.
- Understand variation in mother-pup bond to inform predictive criteria for future translocations.
- Determine shark movement patterns to characterize overlap in time, space and degree with preweaned pups.
- Determine spatial context of predation intersection of seals and sharks (within and outside of our observational window).
- Refine data collection protocol for shark observations at pupping sites.
- Correlate known/inferred pup attacks and tiger shark presence (from primarily with tag data; also with tower observation, since wariness of tigers to humans is not known to be a factor to their presence).
- Determine the reactions of mothers with pups to extended human presence.

Pup Behavior Methods

When camping on the island or viewing video, staff will routinely collect data on nursing pup movement and mother-pup bonding in the form of a focal follow on a pup. Each focal follow will be 2 hours in duration and consist of scan and all occurrence data collection between scans. Focal follows will be conducted primarily during nighttime hours. Scans will occur on a 15-minute interval. Between scans, the vicinity will be scanned for sharks and certain behaviors (see below) will be recorded on a continuous all-occurrence basis. This data will be entered on the Pup Behavior Form. When a shark is sighted (a rare event), the focal follow will be temporarily abandoned and the Shark Sighting/Attack/Incident Form will be initiated.

At the beginning of the 2-hour session, a pup will be chosen as the focal; the focal pair will then consist of that pup and the adult female nearest it, caring for it at the beginning of the follow. Ideally, each pup will be observed for 1–3 sessions per week of its life (until weaning) during nocturnal hours (if moonlight or night vision permit viewing). Diurnal and crepuscular (dawn/dusk) observation may also occur, but at a lower priority. The choice of the focal pup for the follow will be "random" with the aim of getting data on many pups across development throughout the night. Ideally, the maximum number of pups possible at Trig and Gins will be observed in keeping with other population assessment/camp maintenance duties.

Four types of behavioral data will be recorded:

- Context information (on the Pup Behavior Form)
- Scan samples (on the Pup Behavior Form)
- All occurrence data (on the Pup Behavior Form)
- Seal response to shark (on Shark Sighting/Attack/Incident Form)

Some identical context data is on the Shark Sighting/Attack/Incident Form, if the sighting/attack occurs during a Pup Behavior session, simply write “see Pup Behavior Form #___” for these identical data needs.

Shark Behavior Methods

A 4-page form is filled out when a shark is sighted from land, sea (fishing or tagging skiff) or land-based camera, and whether it concludes in an attempted attack or incident (wounding, killing of a seal) or not. Information surrounding a pup disappearance will also be recorded on this form. Complete only the pages and sections that are appropriate to the situation.
If a shark sighting occurs, record the shark’s distinguishing features and use the sketch as desired/necessary. Shark behavior will be recorded for the duration of the shark encounter, capturing information on the shark’s behavior as it changes. For example, the ‘1’ column is filled out to contain the following information: a shark is seen patrolling (code 2) in 6–10 m of water at a distance of 30 m from shore at 1000 hours; there is no obvious response of the mother-pup pair nearest it (NONE) and no human action is taken and, therefore, there is no shark counter-response (last two cells are then left blank). Then, if the shark changes behavior, the ‘2’ column is filled out to indicate this change and includes information as follows: direct approach (code 3) in 3 m, at the shoreline (WW for wave wash), initiated at 10:15 am, the seal pair response is move up the beach (MOV_L), human action does not occur (NONE or leave blank) and the shark responds by leaving (VAC). The sighting end time is recorded as 1018 hours, when the shark left the area. Notes are written below the table to indicate that the shark left the islet to the southwest, through a channel opening between coral heads.

SHARK SIGHTING /ATTACK/ INCIDENT
(circle one)

Date: ____________ Begin Time: ________ End Time:__________
(MM/DD/YY)

OBSERVATION:	ground	tower	boat	camera	other

CONTEXT

Weather conditions:		CLEAR	CLOUDY	RAIN	
Sea conditions (beaufort):	0	1	2 3	4	
Tidal stage:		LOW	HIGH	SLACK	
Substrate bottom:	SANDY	LIVE CORAL	RUMBLE	OTHER	
Glare:		LOW	HIGH		
Water clarity:		CLEAR	TURBID/MURKY		

LOCATION
Atoll: FFS
Island: TRIG GIN LGIN EAST TERN ROUND
Section: ______________

Distance to shoreline:	≤ 5m	≤10m	≤50m	≤100m	≤200m

OPEN WATER, GPS: ___________________
Marked on attached map: Y N

SEAL VICTIM INFORMATION
SF Form #: ___________ Photo #s (*of wound or carcass*): ______________
( ) Limited details known because of nature of incident

PUP: Perm or Temp ID: ____________ Sex: M F U

Age class/DOB: ____________ Seen healthy on: ____________
(MM/DD/YY) *(MM/DD/YY)*
Mother: Perm ID: _______ Age class _________
( ) known birth mother ( ) known nurse mother ( ) either/or birth/nurse ( ) unknown

OUTCOME OF ATTACK (*circle all that apply at time of recording***):**

( ) ATTACK ATTEMPT ONLY (*no obvious contact/wounding*)
( ) BITE Severity: 1 2 3 unknown
Location: head/neck midsection peduncle flipper
ventral dorsal left right
anterior posterior
( ) PREVIOUSLY BITTEN (*date:*_________)
( ) DEATH
( ) DISAPPEARANCE (*complete bottom of page 4)*

SHARK BEHAVIOR

CHARACTERISTICS *(circle all possibilities, place 'x' all exclusions)*
Species: TIGER GALAPAGOS WHITETIP GREYREEF UNK
Color and markings: ___________________________
Length: ______ft SMALL LARGE
Shape of fins, teeth: ____
Scars and tags: ____
Individual sighted in past: NTOK LIKELY DEFINITELY
(date: ________)

Photo #s (of shark):____
Body Sighted: SUBMERGED DORSAL DORSAL+CAUDAL
Shark Sketch used: Y N

At timing of sighting (*circle all that apply*):
Activities occurring: CAMPING TAGGING FISHING
IN TRANSIT SEAL PATROL OTHER

Deterrents (*circle if deployed; place 'x' if not functional*):

BOAT SPEAKERS SHIELDS FLOATS OTHER

Observation	1	2	3	4	5	6	7	8
Distance to shoreline (m)								
Depth (m)*								
Time								
Shark Behavior (*code*)								
Seal Response (*indicate P & M*)								
Human Action								
Shark Counter-Response								

Use ethogram codes, if seals are near and/or harassment is conducted, fill in last 3 rows.
**Depth: WW for wavewash/shoreline*

***NOTES** (if **OTH** above, describe; if **VAC** above, describe direction/ route of shark):*

FOCAL FOLLOW CONCURRENT, SEE PUP BEHAVIOR FORM #:_________
If not, complete page 3

SEAL BEHAVIOR

OBSERVATIONS FOR (*circle one*): **sighting attempt/attack**

PUP ACTIVITY AT BEGINNING OF SIGHTING/ATTACK:
(i.d. info on page 1/ *check all that apply*)

Location: land WW water
Distance to shoreline (in meters): _________ Depth (in meters): _________

ALONE W/ MOTHER- distance: _____ W/ OTHER SEALS- distance:_______

( ) Lying still
( ) Entering water
( ) Splashing, actively moving
( ) Floating, little or no motion
( ) Swimming/ active
( ) Subsurface or diving activity
( ) Leaving water

MOTHER ACTIVITY AT BEGINNING OF SIGHTING/ATTACK (*check all that apply*):

( ) Normal floating/swimming
( ) Splashing/actively moving
( ) Thrashing/flailing/ lunging/chasing/ biting shark
( ) Diving
( ) Unaware/ uninvolved
( ) Oriented toward/ uninvolved
( ) Vocalizing
( ) Other activity as specified: ________________________

NUMBER OF OTHER SEALS NEARBY:
Mother/pup pairs on islet:________ Mother/pup pairs in water:_______
Weaners on islet: ______ Weaners in water:_______
Other:____________

NOTES:

If attack occurred, complete page 4.

ATTACK DETAILS

At time of initial strike (*check all that apply, number activities in order of occurrence*)**:**
( ) Shark did not contact victim
( ) Behavior unknown
( ) CODE 4 straightaway approach to victim
( ) CODE 4 straightway approach to victim, passed close by other(s) in water
( ) CODE 5 minimum of turmoil, victim initially unaware of situation
( ) CODE 5 sudden violent interaction between shark and victim
( ) CODE 5 minimum of turmoil, associate seal (*mother*) initially unaware of situation
( ) CODE 5 sudden violent interaction between shark and associate seal (*mother*)

During subsequent strikes (*check all that apply, number activities in order of occurrence*)**:**
( ) Only one strike occurred
( ) Behavior unknown
Multiple/repeated deliberate strikes/attempts occurred, and:
  ( ) Shark behaved in a frenzied manner
  ( ) Released initial hold, quickly bit victim again
  ( ) Released victim, then followed/pursued victim towards shore
After releases seal:
  ( ) Remained in immediate area of attack
  ( ) Left area of attack, general direction:_________________________
  ____

PUP DISAPPEARANCE

Last date pup was sighted alive: ___________________
Apparent condition of pup at last sighting: ___________________
Last date of observation of suspicious male seal behavior: ___________________
Last date of observation of heightened seas: ___________________
Last date of observation of stormy weather: ___________________
Last date of observation of high winds: ___________________
Last date of observation of sharks/species: ___________________

Upon realization of pup disappearance, mother (that was last seen with it) was (*circle all that apply*):
( ) Absent
( ) Present on land
( ) Present in water
( ) Sleeping/lying still
( ) With different pup
( ) Vocalizing
( ) Searching
( ) Circling
( ) Appeared frantic because:_________________

APPENDIX G: PROPOSAL FOR LIMITED SHARK REMOVAL IN SHALLOW WATERS

The following describes a proposed plan of limited shark removal at FFS as described in the approved Programmatic Environmental Assessment (PEA) for Shark Predation Mitigation submitted by HMSRP in March 2009. HMSRP sought permission to conduct these activities in 2009 but withdrew this request in April 2008. However, this represents HMSRP's methods for the possible implementation of this action in the future and is included to possibly continue discussions on this action. All methods described within this appendix have been approved for implementation by HMSRP at FFS previously (years within the 2001–2007 period).

A limited number of Galapagos sharks in shallow waters near pupping sites would be removed from FFS (up to 40 individuals across a 2-year period). A crew of 2 to 3 familiar with safe and effective methods for shark fishing/removal would be tasked with conducting boat surveys and fishing/removing Galapagos sharks that they encounter in the vicinity of pupping sites (location depending on conditions required for fishing technique used). Boat surveys would occur during daylight hours at select times/days around each main pupping site on a regular basis throughout the field season. Additionally, if observers sight a shark from shore of a pupping site (ground or observation tower if/when erected on Trig Islet) they would alert the fishing crew, who would commence fishing at that time. If the fishing crew deems a removal personally unsafe or unfeasible, they would attempt to harass the shark away from shore by throwing coral and/or herding the shark into deeper water. Shark fishing and removals would be conducted primarily at those locations previously identified or suspected of having the greatest likelihood of catching predatory Galapagos sharks. Similar sites may be identified in the vicinity of the Gins Islets or other less frequently used pupping sites.

Sharks would be removed by one or a combination of four fishing techniques: hook and line, spear or harpoon from shore, bottomset, and drum line. For the hook and line technique, a line would be baited with tuna, shark or other large bait and fished from shore or from a small boat in water up to 50 m from shore. Once a shark has been targeted for removal, the line would be baited. Bait soak time would be limited to 1 hour following the last sighting of a targeted shark to reduce the possibility of attracting additional sharks to the area. Currents would be noted, and the bait would be placed in an area that would avoid excessive risk of scent emanating from the bait to attract other sharks or put seals at additional risk. Gear would be tended to ensure that only Galapagos sharks are hooked. No personnel would enter the water during fishing activities.

A spear gun or harpoon may be used from shore or small boat near to shore when a shark is observed to be very close to the shoreline. A barbed shaft, shot from a spear gun or delivered by hand, would be attached to wire cable and connecting line that would be used to retrieve sharks to the beach for the purpose of euthanizing them.. The spear gun may be powered by elastic bands, as commonly used by sport divers, or by a small caliber (.223) cartridge. In all instances, the spear or barbed head of the spear would be tethered by line so that the shark can be brought to shore for the administration of euthanasia.

The number of hooks attached to each bottomset line would vary. In 2009, no more than 5 hooks would be deployed at one time, on a ~ 100-ft line, as submitted in the application for a permit from the Monument. A report to the Monument would be submitted for review after 5 Galapagos sharks are taken to determine if more sharks could be taken by this method. In subsequent years, status reports would be prepared whenever 5 Galapagos sharks are taken, however, fishing may continue to meet stated objectives.

CPUE (hook hours) of Galapagos sharks using handlines in the shallow waters near pupping sites has been documented at 0.015 (hours fished using one hook) (Lowe et al. 2006), so substantially more than 5 hooks simultaneously deployed would likely be required to catch up to 20 sharks in a pupping season (May through September). Nonetheless, boat size and personnel constraints would limit the number of hooks (and, therefore, length of bottomset) so no more than 20 hooks could be deployed simultaneously.

The bottomset would be attended appropriately at all times by short soak times or otherwise be within the view of the fishing crew. The crew would also be experienced in the use of turtle dehooking devices, with dehooking devices on board at all times. However, the small number of hooks, the use of large fish bait, and the use of large circle hooks substantially decreases the potential for a turtle hooking.

The gear would be deployed and retrieved by hand from a small boat, with short soak times of a maximum of 5 hours, and would be checked in between when hooking is evidenced by observation of the attached marker device. The marker device would comprise a buoy with a flag to designate each end of the gear and would be connected to the monofilament mainline using a ½" diameter polypropylene buoy line. A brummel hook or similar type snap-on hook would be used to connect the buoy to each terminal end of the gear and then anchored to the seabed with a mushroom type anchor or other anchoring device depending on the type of seafloor substrate. The gear would be deployed and anchored on sandy bottom, avoiding live coral areas.

The most effective time for fishing for sharks is at night. However, NMFS personnel are not permitted to be in a small boat in the dark. Therefore, fishing could be conducted at dawn and dusk, as long as all lines are pulled and personnel are on shore before dark.

Measures to prevent seal and turtle entanglement in the buoy line would include shielding the buoy line with segments of a PVC pipe, or modifying the shape of the float buoy to add a rubber, tapered extension, a recent development to prevent cetacean and pinniped entanglement in float buoys. Any entanglement or hooking of a monk seal or sea turtle by the equipment would result in immediate cessation of fishing, pending review of methodology and consultation initiated with NMFS per the ESA. A drumline with a single hook could also be used. The drumline method uses an air- or foam-filled drum or large buoy, with an attached chain trace and single baited circle hook, size 14/0 to 20/0, shackled to the other end of the chain trace. Bait would be the same as for bottomset fishing described above. The hook is suspended approximately 3 m above the seafloor. A ground line is also shackled to the drum with a swivel and then attached to a Danforth or CQR anchor on the sandy bottom substrate. A scope of three to four times the water depth would be used. Precautions to prevent entanglement would be identical to those described for the bottomset method. The locations of sets would be in the sandy channels in the vicinity of pupping sites. This method may be used in addition to the bottomset method described above.

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APPENDIX H: PROPOSAL ON SHARK REMOVAL USING EXPANDED BOTTOMSET FISHING IN DEEPER WATERS

The following describes a proposed plan of expanded shark removal at FFS as described in the approved PEA for Shark Predation Mitigation submitted by HMSRP in March 2009. HMSRP has not sought permissions to conduct these activities; extensive consultations with all stakeholders, especially a number of leaders of Native Hawaiian Community groups, would occur first. However, this represents HMSRP's ideas on this possible future action and is possibly a starting place to initiate discussions.

Using expanded bottomset gear represents an increased effort to contain the Galapagos shark threat when other methods of containment have failed. This method has proven to be effective in capturing Galapagos sharks at FFS in the past (Taylor and Naftel, 1978; DeCrosta, 1984;Vatter, 2003; Lowe et al., 2006; C. Meyer, unpubl. data). The expected take of Galapagos sharks from this method is not likely to adversely impact the greater FFS Galapagos shark population as assessed in ECOPATH/SIM models (NMFS, in prep.; Harting et al. in prep.). Expanded bottomset fishing in areas adjacent to pupping sites at water depths slightly greater than past efforts may improve catch rates and circumvent shark wariness to humans (see Premises in Section III).

Historically, expanded bottomset fishing is the most efficient and effective way of capturing Galapagos sharks at FFS to date (Taylor and Naftel, 1978; DeCrosta, 1984; Vatter, 2003; C. Meyer, unpubl. data). Futhermore, CPUE estimates (sharks/hour per hook) of Galapagos sharks appear to increase with water depth (0.015 within the atoll; 0.04 in the deep lagoonal areas; 0.15 outside the atoll). (See Section 1) Several studies and commercial operations have demonstrated the effectiveness of this technique for capturing Galapagos sharks. For example, commercial bottomset fishing occurred in FFS in July and October 1999, removing more than 50 Galapagos sharks, demonstrating that this is a highly effective way of capturing sharks in the NWHI (Vatter, 2003).

With this method, we expect to capture a greater number of Galapagos sharks of varied life history and behavioral characteristics than with previous limited methods. Lethal removal would be limited to adult Galapagos sharks (as determined by pre-caudal length; DeCrosta, 1984); however, observation of shark predatory behavior or its proxy and proximity of Galapagos sharks to pupping sites would not be prerequisites because individual predation history would not be discernable prior to capture.

We expect that increased fishing pressure in targeting adult Galapagos sharks at water depths of approximately 60 m (10 fathoms) to 72 m (12 fathoms) within 1 mile of pupping sites (Trig, Gin, Round Islets) at FFS would include a significant proportion of this predatory subset, reducing this predation threat overall and resulting in a corresponding decrease in preweaned pup loss (Table 1). The removal of 40 individuals is expected to be a small fraction (0.01–5.7%) of the greater population located at FFS (see estimates in Section 2).

When used in the past, these methods for capturing sharks have had a minimal impact on the physical environment and the other species that use it. For example, bycatch was restricted to a few sharks during 6850 soak hours with 1570 hooks in a 2009 sonic tagging study on sharks at FFS (C. Meyer, unpubl. data). No monk seals or green turtles were caught during any of these deployments.

Date	Study	Sets with Galapagos sharks	Soak hours	Hooks per set	Set depth (Fm)	Bait	Galapagos sharks caught
5/77	Taylor & Naftel 1978	1	n/a	32	15–20	fish, shark	2
11/78, 3/79, 10/79, 5/80, 10/80	DeCrosta 1984	28	12	16–32	20	n/a	34
7/99; 10/99	Vatter 2003[3]	2	~ 20	420	35	fish, shark, ray	52
6/08–8/08; 5/09–8/09	C. Meyer, unpubl. data	unknown	6850	5–10 (1570 hooks total)	unknown	tuna, shark	12 in 2008; 68 in 2009

Table 1.--Galapagos sharks catch at FFS using bottomset fishing gear.

Removals may contribute to filling critical gaps in our knowledge about Galapagos shark diet, population structure, and abundance at FFS. Diet analysis would be conducted on all caught sharks by examining their stomach contents, which may include genetically screening for monk seal tissue. Shark tissue samples would be retained for future DNA extraction and microsatellite analysis to determine effective population size if the total number of Galapagos sharks caught approaches at least 40 individuals. An estimate of minimum population size can be identified by the asymptote of a curve relating the number of distinct genotypes to the number of samples, given a set of sufficiently heterzygous microsatellite primers for the species. Additionally, the estimated rate of gene flow between FFS and nearby atolls, such as Laysan and Mokumanana, may be possible in the future if samples are collected from these sites as well. Change in population structure derived from growth curves may also be possible if pre-caudal lengths of all Galapagos sharks caught are compared to those from previous studies, and sample sizes are sufficient (DeCrosta, 1984). The proposed expanded bottomset fishing methods mirror data collection methods used by shark researchers in previous years. Therefore, CPUE estimates would be directly comparable to those determined by previous researchers and may inform them of the effects of Galapagos shark population growth and change. In summary, these analyses would greatly improve our baseline understanding of the current dynamics of the Galapagos shark population at FFS. If expanded removals occurred

[3] C. Boggs, NMFS PIFSC, Honolulu, Hawaii. Pers. commun., 1999.

during the period that the sonic tags that were inserted in 68 Galapagos and 40 tiger sharks in 2009 were active (their batteries are expected to expire in 2011), then the the response of the greater shark community (represented by these individuals) could be examined.

Action Contingencies

Expanded removal would be warranted if deterrents and/or limited removal methods are not successful in reducing the number of pups lost to predation to goal levels (see detailed contingencies below). Given the reasonable effort expended by HMSRP, the limited removal and use of various deterrents has, in the past, not limited preweaned pup predation to desired levels. The lack of efficacy and the feasibility of limited removal and deterrents are likely to continue to occur as a result of experienced low CPUE, few shark observations, and/or lack of effective equipment (deterrents and fishing gear).

This more expansive/less specific method of shark removal would be implemented once HMSRP documents a shark predation incident (inferred or confirmed pup loss or confirmed bite) in a given season and if:

(1) The prior season's limited removal was unsuccessful because no Galapagos sharks were removed given a reasonable effort, ***OR***

(2) The prior season's limited removal was successful at removing multiple Galapagos sharks at one or more sites, subsequent pup loss decreased at those sites, but atoll-wide pup loss was not within the specified goal range (0–2 pups or 5% of the annual cohort, whichever is less/season), ***OR***

(3) Acoustic shark tag data further substantiate that a small subset of site-specific Galapagos sharks is involved in preweaned pup loss. A panel of experts at a Workshop held by HMSRP on this issue concluded that expanded removal was likely warranted if the Galapagos shark population at FFS could be characterized as such (NMFS, 2009 in prep.). Data would indicate that:

Small means: A minority (greater than 1 individual and less than one third of individuals tagged) of the total sampled Galapagos shark population consistently frequents at least one of the five pupping sites within a distance of approximately 500 m [NMFS WII p10] from shore, *AND*

Subset means: Their presence at pupping sites is statistically greater than the population-wide incidence during the pupping season, based on the tagged population of Galapagos sharks (HIMB study), *AND*

Site-specific means: This subset remained within FFS atoll environs (approximately the 180-m contour based on DeCrosta, 1984, but depending on receiver coverage) for the entire pupping season for which pup loss occurred at typical levels (~15–20% of pups born per year)

OR

(4) Predation is occurring at catastrophic levels (≥ 50% of pups born by the middle of the pupping season are shark mortalities (confirmed or inferred) and/or suffer near-lethal bites (severity 2–3) atoll-wide.

Conversely, if any of the following conditions are met, then the expanded removal of Galapagos sharks will not be initiated or would be discontinued if initiated:

(1) The acoustic tag data indicate that a majority of the tagged Galapagos shark population frequents pupping sites during the pupping season and that at least some of the majority of sharks disperses to other atolls within this time period, ***OR***

(2) Evidence suggests that the expanded removal of Galapagos sharks may inadvertently increase shark predation on pups. This effect will be determined to be true or false when a higher proportion of pups born subsequent to the initiation of the removal of sharks suffer shark-mortality (confirmed and inferred) and/or near-lethal bites (severity 2–3) as compared to the number of incidents occurring during the similar time period in the two seasons prior, ***OR***

(3) An unusual shark mortality event unrelated to the HMSRP program, such as a disease outbreak or entanglement occurs in which a high number of Galapagos sharks die within the 30-fm depth contour of FFS. DeCrosta (1984) identified the 'border' of FFS at the 30-fm depth contour in his study examining Galapagos shark abundance, ***OR***

(4) Observational data demonstrates that tiger sharks preyed on multiple preweaned pups within one pupping season. Observational data will include a witnessed accounting of charging, chasing, biting, or attacking behavior of a tiger shark on a preweaned pup.

Action Duration

If the above conditions are met and the application of expanded removal is initiated, it would continue until at least one of the following conditions is met, with one notable exception:

(1) 40 sharks have been removed in a single season, ***OR***

(2) Subsequent preweaned pup loss has decreased to zero for the remainder of that season and at least half of the typical pupping season is included in that remainder, ***OR***

(3) The action has continued for two consecutive seasons. If a statistically significant correlation exists between the number of Galapagos sharks removed and the decrease in the proportion of preweaned pups lost to shark predation (confirmed and inferred), then continuing the action will be evaluated and considered.

Combining Actions in the Toolbox

Expanded removal may occur singly or concurrently with other management actions to mitigate preweaned pup losses, including deterrents (human presence, proxies, electromagnetic devices), limited fishing in shallower waters, and barriers, as well as actions taken by other components of the HMSRP, including moving weaned pups. An ability to apply multiple management actions simultaneously allows HMSRP to respond to changing the dynamics of the FFS ecosystem and the movement and behavior of both Galapagos sharks and monk seals. However, if multiple fishing methods are deployed at one time, the total number of hooks and associated amount of bait would be closely monitored and limited if necessary to avoid attracting unusual numbers of sharks within a 200-m radius of any pupping site.

Expanded Bottomset Methods

Crew: A crew made up of up to 5 members familiar with bottomset fishing would be tasked with setting gear and dispatching of up to a maximum of 40 adult Galapagos sharks in one pupping season.

Gear: Expanded bottomset gear proposed for use here is patterned after those successfully used in previous studies (Table 1). Expanded bottomset gear would include horizontal weighed polypropylene ground line with circle hooks (largest commercially available 16/0– 20/0 Mustad) on steel swivels or steel leaders on gangions (approximately 6 to 12 ft of galvanized cable or microfilament line) set on or near the ocean bottom on sandy or rubble substrate (non-coral) attached to two or more vertical dropper lines with floats and weights. The number of circle hooks per set would average 32, reduced if initial catch rates are exceedingly high in a single set or as the shark removal quota is approached. The number of hooks could also be increased to 48 if initial catch rates are exceedingly low in a single set. Based on calculations by Vatter (2003), catch rates are less than the number of hooks deployed. Furthermore, catch rates here are expected to be lower than that experienced in previous studies (Table 1) because soak times used by HMSRP would be substantially shorter than in those studies. Therefore, the number of hooks deployed may be more than those used in previous studies to account for this difference in methods.

Bait may include elasmobranch species, including dispatched Galapagos sharks caught with this method, tuna, mackerel, and/or other fish species. Sets would be made in depths of 60 m to 72 m (10 fathoms to 12 fathoms) balancing the need to set in deeper water than previous efforts as well and be located adjacent to pupping sites. However, sets would not be made within 200 m of pupping sites; preweaned pups were not known to swim greater than 200 m from shore in one study that followed 30 mother-pup pairs for the entire nursing period (Boness, 1990). Sets would be made and retrieved during day or nighttime hours. The latter would focus on predawn soaks retrieved during daylight hours. Soaks would be for approximately 3–6 hours and made back-to-back for a maximum of 12 consecutive hours. The gear would be deployed and retrieved from a small boat or fishing vessel; a winch will likely be used.

Information on each set would be recorded, including gear set and retrieval times, latitude and longitude of both ends of the bottomset, bait used, weather conditions, hours soaked (including time of day), depth of fishing sea surface temperature, sea state, number of hooks, buoys, anchor weights, number of hooks lost, number of hooks straightened, number of hooks with targeted catch, number of bycatch caught and released, with condition at release and species, length of groundline (nm), species caught, number, relative condition, and sex. Tape measure and calipers would be used to measure shark pre-caudal length. A post-fishing report would be prepared at the end of each season and submitted to the Monument

Post-Catch Procedures

Hooked sharks would be brought adjacent to the vessel or aboard and euthanized with a 0.44 caliber bang stick. As agreed upon by USFWS and NMFS (August 18, 2001), information concerning the removal of each shark would include environmental conditions at the time of removal, criteria used to determine the shark targeted for removal, identifying tags and physical features of the shark removed, history of previous shark sightings, removal methodology, and method of euthanasia. Information and materials collected from each shark carcass would include morphometric measurements, genetic samples, stomach contents, vertebrae and reproductive status. Tissue samples from sharks would be analyzed to quantify compounds of potential concern at acceptable detection limits to include total metals, polychlorinated biphenyls, organochlorine pesticides, percent lipid and moisture, and fatty acid profile analysis for detection of possible monk seal consumption. Teeth and ventral (belly) skin would be retained and made available for cultural purposes. Vertebrae and skin samples would be collected for isotope to detect marine mammal consumption and genetic analysis. Stomach contents would be retained for diet analysis; genetic screening for monk seal DNA may occur on unidentified digesta if necessary. Preservation of samples would be as follows: vertebrae samples in 95% ethanol or frozen and tissue samples for DNA analysis in a 20% dimethyl sulfoxide solution or frozen. After all samples and data have been collected, shark carcasses would be discarded at several of the closest deepwater locations outside FFS; every attempt will be made to distribute carcasses at several points to avoid infusing one location with an excess of biomass.

Hawaiian cultural protocols, based on extensive practitioner input, would be included in all shark removal efforts. Ongoing consultation with Hawaiian practitioners would advise fishing personnel on traditional fishing techniques, along with the feasibility for an on-site practitioner to conduct activities, including the collection of shark parts for cultural use (remains to be determined). Any species other than Galapagos sharks that are caught as part of this project would be released immediately alive. Bycatch may include tiger sharks, reef sharks, or other top predators such as ulua. We anticipate that bycatch would be minimal, as the hooks should be too large to catch small reef sharks or ulua, and would be small enough to be bent (straightened) by large tiger sharks. Moreover, circle hooks are less prone to accidentally snag nontarget animals and, if snagged, tend to catch the animal in the mouth, where it can be easily removed with no injury. Furthermore, use of fish rather than squid substantially reduces the potential for sea turtles to swallow the hook (NMFS, 2009). If a monk seal were observed approaching the fishing gear, the management action (expanded bottomset) would discontinue at this location.

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APPENDIX I: PRELIMINARY PROPOSED BARRIER DESIGN

The following is a preliminary description of a design for a semi-permeable barrier to prevent shark activity inshore at pupping sites and included in the Programmatic Environmental Assessment (PEA) on Shark Predation Mitigation submitted in March 2009 by HMSRP. In the PEA, this mitigation action is not considered in detail because information gaps on the impact of such a deterrent need to be thoroughly examined first before permission can be sought for its implementation. This description serves to introduce the idea and the development required if barrier construction is sought as a feasible predation mitigation action in the future.

Barriers to prevent sharks from entering nearshore areas have the potential of decreasing the number of preweaned pups that are preyed upon because such devices could increase the safety zone for young seals to include both land and water. HMSRP has observed Galapagos sharks approaching, lunging, chasing and biting preweaned pups in water as shallow as the shoreline/wave wash zone. Preweaned pups enter the water to thermoregulate, practice swimming, learn about the ocean environment, and to otherwise stay in close contact with their mothers. Thus, the objective of a barrier is to prevent nearshore approaches by sharks while allowing preweaned pups to develop normally and experience the land and water environments as they typically would. Any barrier must also allow the typical movement between land and water of other wildlife, especially breeding female monk seals and nesting/basking green turtles. This action is not expected to have adverse impacts on the coral reef ecosystem, including monk seal and Galapagos shark populations, and will likely be developed in the future. A general description follows providing a list of pilot studies that would aid in further developing this action for implementation at FFS.

Barriers represent a nonlethal means of excluding predatory sharks from areas frequented by preweaned pups when other means such as deterrents and limited removal have proven ineffective at bringing pup losses down to goal levels. Barriers would be semipermeable with openings to allow monk seal and green turtle entry but prevent the passage of elasmobranchs, thus having the potential to swiftly reduce the amount of time preweaned pups are available as prey. As such, efforts required to construct, install, maintain and monitor barriers should be weighed against the potential benefit of this strategy to mitigate predation and the occurrence of direct, purposeful loss of animal life.

Access to nearshore areas despite its hazards is important to the development of the Hawaiian monk seal. A study following 30 FFS mother-pup pairs from birth to weaning demonstrated that preweaned pups entered the water 5.6 (SE 1.7) times a day, spending 24.1% (SE 6.86%) of the day in the water (Boness, 1990). Preweaned pups were an average of 0.2 m (SE 2.57 m) from their mothers when on land and 1.3 m (SE 3.46 m) from their mothers when in the water, based on daytime observations (Boness, 1990). Average distance between pup and mother did not significantly change during the first 5 weeks of life; thereafter, distance increased as weaning approached. Witnessed accounts suggest Galapagos sharks approach preweaned pups despite the close proximity they keep to their mothers. Shark predation on pups occurs throughout pup development; thus mother-pup distance is not likely to be a driving factor of this lethal interaction.

Possible Impact on Seal Movement

A barrier with openings may influence some seals' movement patterns by making it more difficult to swim out farther from shore as they might normally. Absolute distance from shore that preweaned pups venture in an effort to remain with their mothers is expected to be highly variable, depending on where a mother decides to swim and the topography of the island and its environs. At East Island, preweaned pups on the southwest side never ventured farther than 70 m, although this is the extent of the shallow reef habitat at this location (Boness, 1990). This maximum distance is likely to be different for other pupping sites in which the shallow reef habitat extends farther. A barrier with openings may influence the length of time required for a seal to enter the nearshore area/beach. Barrier design would include multiple openings in an attempt to mitigate this potential side effect.

Possible Impact on Galapagos Shark Behavior

Shark experts familiar with Galapagos shark behavior and movement suggest that a Galapagos shark that is found in shallow water near pupping sites is likely an opportunistic pup predator; such nearshore behavior is highly unusual for the species on a global level (NMFS, 2008; Meyer, MHI tagging data). A barrier to exclude sharks from nearshore areas of pupping sites is, therefore, not likely to negatively impact the behavior or survival of the greater Galapagos shark population at FFS.

General Design

A semipermeable barrier would be constructed out of multiple floating panels of a tensile, lightweight fencing material, such as that used in aquaculture pens (e.g., Kikkonet, lightweight mesh which has 4/5 tensile strength of 10-gauge steel wire, but only 1/5 the weight. The mesh is double twist knitted to prevent serial ripping, coated to be rust-proof and resistent to sea-water damage, www.kikkonetusa.com). The lattice design of the material would be chosen to maximize strength during a water surge, minimize entrapment of debris and small fish/invertebrates, and avoid entanglement of large animals or their body parts. Adjacent panels would be spaced to create approximately 2-m openings between them that function as wildlife passageways. The length, width and height of each panel would depend on the bathymetry, current, and wave surge of the location. Parameters would be chosen that support the secure upright positioning of each panel at each location. Panels would be attached to surface floats along their top side. Panels will be secured at their bottom corners by anchor (PVC tube shafts to cover line) when on sandy substrate or by being shackled to driven stakes/pipes if on hard pan or rubble substrate. Panels would be placed to avoid laying anchors or driving stakes into living coral.

Barriers would be erected on a seasonal basis (duration to coincide with the main pupping season at FFS: May–September) at pupping sites with a history of numerous pup births and shark incidents, possibly Trig, Gins and Round. This action would not occur at East or Tern

Islands because of their high human, green turtle and albatross traffic and historically low shark incidents; although, initial pilot feasibility studies may occur off of Tern because of the ease of human monitoring there. The number of panels will depend on the area to be protected. Areas to be protected may be restricted to select segments or sides of islands where mother seals typically birth. Current observations and historical data on birthing will be examined to guide placement.

Electromagnetic devices (e.g., Shark Shield) designed to deter elasmobranchs will flank each opening. The impact zone of these devices on Galapagos sharks is at least approximately 1 m based on field trials with wild Galapagos sharks near Haleiwa, Hawaii. The size of barrier openings is based on this impact zone; if electromagnetic devices are found with a greater impact zone, opening size will be increased. These devices operate on rechargable lithium batteries. If the technology is improved to work on longer-life DC batteries (solar powered), then cable used will be covered in PVC tubes to prevent entanglement hazard. Power stations will be placed on the island (DC batteries and solar panels) as described in section 2.2.1.2. for underwater speaker deterrents.

Maintainence of barriers is expected to be similar to that of net-pen enclosures designed to retain juvenile monk seals in care programs by HMSRP in the past. Materials described here differ from those of past net-pens because they are sturdier, stronger and include anti-fouling coatings than materials used in temporary net-pens, and as such, the day-to-day maintenance is expected to be less. Any trapped debris or growing algae would be removed to be routinely cleaned with a scrub brush or other such implement.

Pilot Studies on Feasibility and Impacts

The following tests, likely to be performed before the use of semi-permeable barriers at FFS, is considered more fully:

(1) Determination that seals (captive monk seal or other phocid) will navigate through a 2-m opening between barrier material when installed in a way similar to above description in a enclosed area (e.g., captive tank or lagoon).

(2) Determination that green turtles (captive) will navigate through a 2-m opening between barrier material when installed in a way similar to above description in an enclosed area (e.g., captive tank or lagoon).

(3) Determination that Galapagos sharks (captive or wild) will not enter a 2-m opening flanked by operating electromagnetic devices between barrier material when installed in a way similar to above description.

(4) Determination that barrier material will remain secure and erect when tested in the range of current, wind, wave surge and depth condtions expected to occur around pupping sites at FFS.

(5) Determination that barrier material and securing equipment will not foul or cause an aggregation/accumulation of debris or living organisms found in the nearshore environment to an inappropriate level given a reasonable maintenance schedule.

(6) Determination that barrier material and securing equipment can be quickly removed by as few as two people in the event that an emergency, such as inclement weather, were to occur at FFS.

Availability of NOAA Technical Memorandum NMFS

Copies of this and other documents in the NOAA Technical Memorandum NMFS series issued by the Pacific Islands Fisheries Science Center are available online at the PIFSC Web site http://www.pifsc.noaa.gov in PDF format. In addition, this series and a wide range of other NOAA documents are available in various formats from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, U.S.A. [Tel: (703)-605-6000]; URL: http://www.ntis.gov. A fee may be charged.

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P. KLEIBER, S. CLARKE, K. BIGELOW, H. NAKANO, M. MCALLISTER, and Y. TAKEUCHI
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